Technical Note 12

Conservation Activities in Organic Farming Systems

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Introduction

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This technical note is designed to help conservation planners apply the Conservation Practice Standard (CPS) Organic Management (Code I823) and other NRCS conservation activities in the conservation planning process. Information provided here will help conservation planners and service providers understand organic agriculture principles and the National Organic Program (NOP) regulations and how they relate to the conservation of soil, water, air, plant, animal, energy, and human resources. Organic conservation strategies and practices that are not covered by current conservation practice standards are explored in depth.

The organic agriculture movement emerged during the 20th century in response to widespread concerns about soil degradation, declining crop and livestock health, and diminished quality of farm products resulting from intensive cultivation, inadequate crop rotations, and the increasing use of soluble mineral fertilizers and chemical pesticides. The organic farming method, codified in the USDA NOP regulations, emphasizes the development of healthy, living soils and biodiverse agroecosystems as the foundation of sustainable and successful production. NOP § 205.2 defines organic production as:

> *"A production system that is managed in accordance with the [Organic Food Production] Act [of 1990] and [NOP] regulations … to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity."*

As stated in NOP § 205.200, general production requirements for NOP-certified organic operations include:

> *"Production practices … must maintain or improve the natural resources of the operation, including soil and water quality."*

NOP § 205.2 provides a broad mandate for conservation by defining "natural resources of the operation" as:

> *"The physical, hydrological, and biological features of a production operation, including soil, water, wetlands, woodlands, and wildlife."*

One key aspect of NOP-certified organic agriculture that distinguishes it from other production systems is the prohibition of most synthetic inputs, including manufactured soluble fertilizers, conventional pesticides, herbicides, fungicides, and nematicides. NOP-allowed alternatives such as botanical pesticides are used only when cultural, physical, and biological controls fail. The organic method avoids synthetic chemicals and limits the use of other toxicants for several reasons:

- To protect soil health, soil life, and biological functions essential to production.
- To protect surface and groundwater and other natural resources.
- To protect beneficial insects, wildlife, and other nontarget organisms.

- To enhance crop, livestock, and human health.
- To protect farmers, farmworkers, and consumers.

NOP §§ 205.202 and 205.105 prohibits most synthetic substances as follows:

> *"Any field or farm parcel from which harvested crops are intended to be sold, labeled, or represented as "organic," must:*
>
> > *"Have had no prohibited substances … applied to it for a period of 3 years immediately preceding harvest of the crop."*
>
> *"To be sold as … "organic," … the product must be produced and handled without the use of synthetic substances and ingredients, except as provided in [the National List of synthetic substances allowed for use in organic production.]"*

Because synthetic agrochemicals are prohibited, organic farmers and ranchers rely on biological processes and natural materials to manage soil, nutrients, water, crops, livestock, pests, weeds, pathogens, and beneficial organisms for successful production. As a result, organic producers place greater emphasis on diversified crop rotations, cover crops, compost, other organic soil amendments, and crop-livestock integration.

NOP regulations also address livestock (origin, living conditions, health care, feed, access to pasture), plant propagation (organic or non-GMO seed and planting stock), and management of crop residues (burning allowed only to control disease or promote seed germination).

The goals of the CPS Organic Management include:

- Providing criteria and guidance for organic agricultural conservation activities that are not fully covered in other practice standards.
- Optimizing conservation outcomes of organic systems.
- Helping organic producers meet NOP conservation requirements.
- Helping organic producers achieve their stewardship goals.
  Helping to begin and transitioning organic producers to adopt resource-conserving organic management.

Purposes of this technical note include:

- Describing conservation activities that organic producers commonly implement, how they address natural resource concerns (e.g., greenhouse gases and climate change), and how they parallel, differ from, and complement existing NRCS conservation practices.
- Describing NOP-compliant practices used to manage soil, nutrients, water, other natural resources, crops, livestock, pests, pathogens, weeds, and beneficial organisms.
- Providing research-based practical information on conservation benefits of organic systems and conservation challenges faced by organic producers.
- Providing practical knowledge to help organic producers implement CPS Organic Management and meet NOP regulations and NRCS conservation criteria.

Table 1 outlines the relationships among NRCS resource concerns, the purposes of CPS Organic Management, and NOP definitions and practice standards.

Table 1. Relationships among NRCS resource concerns, purposes for CPS Organic Management, and NOP regulations.

Resource concern	CPS Organic Management purposes	Relevant NOP terms defined, production practice standards, and other requirements
Soil	Improve soil health. Reduce soil erosion.	*Terms defined:* Soil and water quality. *Practice standards:* General, Soil fertility and crop nutrients, Crop rotation.
Water	Reduce transport of pesticides and nutrients to surface water and groundwater. Improve moisture management.	*Terms defined:* Buffer zone, Soil and water quality. *Practice standards:* General, Soil fertility and crop nutrients, Livestock living conditions – manure management, Pasture.
Air	Reduce transport of pesticides and nutrients to air.	*Terms defined:* Buffer zone. *Land requirements:* Boundaries and buffer zones. *Practice standards:* Soil fertility and crop nutrients – residue burning
Air (climate)	Reduce emissions of greenhouse gases.	(No specific NOP regulations)
Plants	Improve plant productivity and health. Reduce plant pest pressure.	*Terms defined:* Wild crop. *Practice standards:* Soil fertility and crop nutrients, Seeds and planting stock, Crop rotation, Pest, weed and disease management, Wild crop harvesting
Animals	Enhance habitat for wildlife, pollinators, other beneficials.	*Terms defined:* Natural resources of the operation, Organic production. *Practice standard:* General
Animals	Improve feed & forage balance. Improve forage for grazing.	*Practice standards:* Livestock feed, Livestock health care, Livestock living conditions, Pasture.

Implementation of this practice requires a whole farm conservation plan. NOP requires each applicant to provide an Organic System Plan (OSP) that documents:

- All production practices and the frequency they are performed.
- All input substances.
- Monitoring practices and record keeping system.
- Management practices and physical barriers that protect organic production areas and products from NOP-prohibited substances.

Alternatively, NOP § 205.201 allows the following option for the OSP:

> *"A producer may substitute a plan prepared to meet the requirements of another Federal, State, or local government regulatory program for the organic system plan, provided that, the submitted plan meets all the requirements of this subpart."*

Thus, the documentation required for implementing CPS Organic Management can meet many of the requirements for the OSP. Coordinating the development of NRCS conservation plans with NOP OSPs can avoid duplication of effort and thereby reduce paperwork burdens for organic producers implementing CPS Organic Management.

Soil Conservation and Soil Health Practices in Organic Farming Systems

Early leaders in the organic sector recognized that sustainable farming relies on healthy soils. Maintaining soil health means replenishing soil organic matter (SOM) consumed during production and nutrients removed through harvest.[1] Key practices include:

- Feed the soil and let the soil feed the crop.
- Return all manure and other farm-generated residues to the soil.
- Make and use compost to enhance soil health and fertility.
- Diversify crop rotations and farm enterprises.
- Plant cover crops for multiple purposes
- Integrate livestock and crop production to optimize nutrient cycling.

The NOP soil fertility and crop nutrient management practice standard provides criteria for these activities (Table 2). NOP § 205.203 criteria for protecting water and soil resources are:

> *"The producer must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials … to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances."*

[1] Lady Eve Balfour, The Living Soil (1943); Sir Albert Howard, The Soil and Health: A Study of Organic Agriculture (1947); Ehrenfried Pfeiffer, Biodynamic Farming and Gardening 26–27 (2nd ed. 1943); Monica M. White, Freedom Farmers: Agricultural Resistance and the Black Freedom Movement (2018).

Table 2. Organic soil health activities and criteria in relation to existing NRCS practices.

Organic Conservation Activity	Complete Coverage in Existing CPS	Partial Coverage in Existing CPS	Topics in Existing CPS	New Criteria for Organic Soil Health Activities
Composting	No	Composting Facility (317), Soil Carbon Amendment (336)	Facility for making and storing compost, Organic C inputs	Making and using compost
Diverse Crop Rotation	No	Conservation Crop Rotation (328)	Minimum 2 crops, substitute crops for contingencies	Min. 3 crops incl. cover crop
Crop-Livestock Integration	No	Prescribed Grazing (528), Silvopasture (381)	Forage quality, water and soil resource concerns	Manure – harvest intervals for food safety
Conservation Tillage	Reduced Till (345) and No Till (329)			Organic tillage practices
Non-Use of Synthetics	No	Nutrient Management (590), Pest Management Conservation System (595)	4Rs of nutrient management, PAMS (prevention, avoidance, monitoring, and suppression) and WIN-PST for pest management	National lists of allowed and prohibited substances

Compost and composting

For centuries before the invention of soluble fertilizers, farmers have returned livestock manure and crop residues to field soils to maintain fertility. Often, these materials were stockpiled until the next planting season, allowing them to decay and become easier to spread.[2] Early in the 20th century, founders of the organic movement refined the composting process and recommended composting to convert organic wastes into a valuable soil amendment, retain and stabilize crop nutrients in manure and other farm-generated residues, and kill pathogens, pests, and weed seeds.[3] They understood that finished compost contains beneficial soil organisms as well as plant nutrients, builds SOM, helps maintain soil structure, enhances the soil's cation exchange and water holding capacity, and releases soluble nutrients more gradually and with less leaching and

[2] Gary Hergert, Rex Nielsen & Jim Margheim, *A Historical Overview of Fertilizer Use,* Univ. of Nebraska-Lincoln: Cropwatch (Mar. 15, 2015), https://cropwatch.unl.edu/fertilizer-history-p1.
[3] Lady Eve Balfour, The Living Soil (1943); Sir Albert Howard, The Soil and Health: A Study of Organic Agriculture (1947); Ehrenfried Pfeiffer, Biodynamic Farming and Gardening 26–27 (2nd ed. 1943); Monica M. White, Freedom Farmers: Agricultural Resistance and the Black Freedom Movement (2018).

volatilization losses than raw manure. Thus, the manufacture and use of compost became a hallmark of the organic farming method.

Making compost entails several steps:

- A combination of nutrient-rich "greens" (manure, slaughter waste, food scraps, succulent plant matter, etc.) and carbon-rich "browns" (straw, stover, tree leaves, chipped brush, etc.) is gathered to make a diverse and balanced mixture of organic materials.
- The materials are chopped (if needed), mixed, and placed in a windrow, static pile, or a bin or other vessel.
- Optionally, an inoculant such as finished compost or healthy topsoil (up to 10 percent of total volume), biodynamic preparations, compost starter, or other commercial microbial product is mixed into the windrow or pile to speed or optimize biological processes.
- As microbial activity accelerates and the mixture heats up, aerobic conditions are maintained by periodic turning (windrow) or forced aeration (static pile or in-vessel).
- Temperature, moisture, and sometimes oxygen and carbon dioxide levels are monitored, and the composting material is turned and watered as needed to maintain optimal temperatures (between 130°F and 150°F) and moisture (40–60 percent by weight) and sufficient oxygen.
- After the hot phase of composting passes and core temperatures drop below 100°F, the pile or windrow is allowed to cure for a few weeks or months, during which nutrients are stabilized and the compost develops a diverse community of beneficial organisms.

Organic farmers use finished compost in several ways:

- As an ingredient of potting mixes to grow vegetable starts and other planting stock.
- In planting holes or seed furrows as a starter fertilizer.
- For broadcasting and mixing into the top few inches of soil to provide season-long slow-release nutrients, suppress crop disease, replenish organic matter, and enhance soil biology.
- To restore depleted soil by spreading heavily (1–4 inches depth) and mixing into the A horizon.

In addition to making a beneficial soil supplement, a well-managed composting process minimizes harmful gaseous emissions and odors, and an effective hot phase (approximately 140°F for several days or longer) kills most pathogens, pests, parasites, and weed seeds, rendering the product much safer. However, composting requires careful management, and incomplete or "cool" composting can yield a less beneficial product that may carry human foodborne pathogens as well as plant pests, pathogens, and weed seeds. Therefore, NOP § 205.203 includes the following criteria for management of animal and plant materials:

> *"Raw animal manure must be composted unless it is:*
> - *Applied to land used for a crop not intended for human consumption;*
> - *Incorporated into the soil no less than 120 days before harvesting a product whose edible portion has direct contact with the soil surface or soil particles; or*
> - *Incorporated into the soil not less than 90 days prior to the harvest of a product whose edible portion does not have direct contact with the soil surface or soil particles;*
>
> *"Composted plant and animal materials produced though a process that:*

- *Established an initial C:N ratio of between 25:1 and 40:1; and*
- *Maintained a temperature of between 131 °F and 170 °F for 3 days using an in-vessel or static aerated pile system; or*
- *Maintained a temperature of between 131 °F and 170 °F for 15 days using a windrow composting system, during which period, the materials must be turned a minimum of five times.*

"Uncomposted plant materials [may be applied to the field without restrictions.]"

Some organic farmers, especially those whose operations include both crops and livestock, make their own compost on-farm. Others purchase compost from a composting facility or vendor whose products have been certified by the Organic Materials Review Institute (OMRI), a State Department of Agriculture, another qualified entity, or the NOP itself as allowable for USDA-certified organic operations. Vendors must provide documentation showing that compost ingredients do not include any NOP-prohibited substances and that the composting process has met the above criteria.

When an on-farm composting process does not meet NOP composting criteria and the mixture includes manure, other materials of animal origin, or post-consumer food waste, the product must be handled as raw manure and the above-listed waiting periods between application and harvest must be observed. Similarly, any amendment of animal origin from off-farm sources that does not meet NOP composting criteria must be handled as raw manure.

Wholly plant-based materials such as leaf mold or yard trimmings can be field-applied without restriction if they have not been exposed to NOP-prohibited substances such as lawn pesticides and herbicides. Organic farmers can often obtain fresh, aged, or cool-composted leaves or chipped brush from municipalities for free or at low cost; however, they must verify that the product is free of NOP-prohibited materials and should check with their organic certifier before using the material.

Research has shown that compost can enhance soil biological function and nutrient cycling to a far greater extent than more concentrated organic nutrient sources such as poultry litter.[4] Compost works in a complementary manner with cover crops and diversified rotations to build

[4] A. Bhowmik, AM Fortuna, L. Cihacek, A. Bary & C.G. Cogger, *Use of Biological Indicators of Soil Health to Estimate Reactive Nitrogen Dynamics in Long-Term Organic Vegetable and Pasture Systems,* 103 Soil Biology and Biochemistry 308 (2016); A. Bhowmik, AM Fortuna, L. Cihacek, A. Bary, P.M. Carr & C.G. Cogger, *Potential Carbon Sequestration and Nitrogen Cycling in Long-Term Organic Management Systems,* 32 Renewable Agric. and Food Sys. 498 (2017); T. Bowles, A.D. Hollander, K. Steenwerth & L.E. Jackson, *Tightly Coupled Plant-Soil Nitrogen Cycling: Comparison of Organic Farms Across an Agricultural Landscape,* PLOS ONE (June 29, 2015), https://doi.org/10.1371/journal.pone.0131888.

soil health.[5] Similar synergies have been documented with manure or a combination of poultry litter and cover crops.[6]

Compost may be especially effective for production in low-rainfall regions with soils low in organic matter, biological activity, P, and other nutrients. For example, in Utah, a single heavy application of finished compost (22 tons dry weight per acre) doubled soil organic carbon (SOC), soil P (which had been limiting), and dryland wheat yields for 15 years, with substantial benefits continuing until at least 26 years after application.[7]

However, more is not always better. Compost is often quite high in P so that its N:P:K ratio does not match crop utilization of these three nutrients. Therefore, using compost to meet a crop's N need will eventually build excess P in the soil. When soil P rises above the optimum range, mycorrhizal fungi that play vital roles in soil and crop health become inactive, thereby compromising the soil health benefits of organic production systems.[8] Excess soil P can also pollute nearby surface waters, which puts the farm out of compliance with the NOP soil fertility practice standard.

Heavy applications of compost or other organic amendments can lead to other nutrient imbalances that may adversely affect soil health or crop yields. For example, uncomposted or poorly composted amendments with a high ratio of carbon to nitrogen (C:N), such as sawdust, can temporarily tie up soil N. Proper management of compost and other organic nutrient sources is discussed in greater detail in "Nutrient Management in Organic Farming Systems."

[5] E.B. Brennan & V. Acosta-Martinez, *Cover Cropping Frequency is the Main Driver of Soil Microbial Changes during Six Years of Organic Vegetable Production,* 109 Soil Biology and Biochemistry 188 (2017); T. Hurisso, S.W. Culman, W.R. Horwath, J. Wade, D. Cass, J.W. Beniston, T. Bowles, S. Grandy, A.J. Franzluebbers, M.E. Schipanski, S. Lucas & C.M. Ugarte, *Comparison of Permanganate-Oxidizable Carbon and Mineralizable Carbon for Assessment of Organic Matter Stabilization and Mineralization,* 80 Soil Sci. Soc. Am. J. 1352 (2016); S. Tavantzis, R. Larkin, A. Alyokhin, M.S. Erich & J.M. Jemison, *A Systems Approach to Optimize Organic Crop Production: Enhancing Soil Functionality and Plant Health to Suppress Plant Diseases and Pests,* U.S. Dep't Agric. (2012), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0210222").

[6] K. Delate, C. Cambardella & C. Chase, *Effect of Cover Crops, Soil Amendments, and Reduced Tillage on Carbon Sequestration and Soil Health in a Long-Term Vegetable System,* U.S. Dep't Agric. (2015), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0223698"); C. Hooks, K.H. Wang, G. Brust & S. Mathew, *Using Winter Cover Crops to Enhance the Organic Vegetable Industry in the Mid-Atlantic Region*, U.S. Dep't Agric. (2015), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0222422").

[7] J. Reeve & E. Creech, *Compost Carryover Effects on Soil Quality, Productivity and Cultivar Selection in Organic Dryland Wheat*, eOrganic (2015) https://eorganic.org/node/14629; J.R. Reeve, P.M. Carr, J.B. Norton, A.R. Jacobson, U. Norton, I.C, Burke, M. Kim, K. Curtis, R, Larsen, M. Yost, T.R. Fortenbery, J.E. Creech & C.A. Eberle, *From compost carryover to compost legacy: intercropping and compost effects on yield, quality, and soil health in organic dryland wheat* (2020), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1020449").

[8] C.B. Gottshall, M. Cooper & S.M. Emery, *Activity, Diversity and Function of Arbuscular Mycorrhizae Vary with Changes in Agricultural Management Intensity,* 241 Agric., Ecosystems & Env't 142 (2017); M. Van Geel, E. Verbruggen, M. De Beenhouwer, G. van Rennes, B. Lievens & O. Honnay, *High Soil Phosphorus Levels Overrule the Potential Benefits of Organic Farming on Arbuscular Mycorrhizal Diversity in Northern Vineyards,* 248 Agric., Ecosystems & Env't 144 (2017).

Diversified crop rotations and crop-livestock integration

Early leaders in the organic sector emphasized the soil health and agroecosystem benefits of crop and enterprise diversity, rotations that include legumes, and crop-livestock integration.[9] Many organic farmers develop complex, strategic, and innovative crop rotations to maximize soil coverage and living root, minimize erosion, build SOM and soil functional biodiversity, increase nutrient and water use efficiency, reduce weed and disease pressure, and improve the financial stability of the operation through product diversification.

Some producers integrate crop and livestock operations by rotating vegetable, grain, or row crops with forages for grazing or hay or by grazing post-harvest crop residues or cover crops. NOP regulations requiring a 120- or 90-day interval between raw manure applications and harvest of organic food crops with or without direct contact with soil also apply to manure deposited by grazing livestock. Grazing of post-harvest crop residues, cover crops, or perennial sod crops in the rotation usually allows the producer to schedule the grazing to meet NOP criteria.

NOP §§ 205.205 and 205.2 provide the following regulation for organic crop rotations:

> *"The producer must implement a crop rotation including but not limited to sod, cover crops, green manure crops, and catch crops that provide the following functions that are applicable to the operation:*
> *(a) Maintain or improve soil organic matter content.*
> *(b) Provide for pest management in annual and perennial crops.*
> *(c) Manage deficient or excess plant nutrients; and*
> *(d) Provide erosion control."*

> *"Perennial cropping systems employ means such as alley cropping, intercropping, and hedgerows to introduce biological diversity in lieu of crop rotation."*

Because organic farmers cannot resort to soluble fertilizers or synthetic pesticides to address production problems, they depend to a greater degree than conventional farmers on a sound and diverse crop rotation for management of soil health, nutrients, weeds, pests, and plant pathogens. Thus, CPS Organic Management sets a higher bar (three or more different crops including at least one cover crop) than the general criteria for CPS 328 Conservation Crop Rotation (two different crops). The cover crop in the rotation must meet the criteria for CPS 340 Cover Crop.

Cover crops play a prominent role in organic cropping systems. For example, surveys have shown that 76 percent of organic field crop farmers use cover crops regularly, compared to just 10 percent of conventional field crop farmers.[10] In another survey of vegetable growers in

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[9] Lady Eve Balfour, The Living Soil (1943); Sir Albert Howard, The Soil and Health: A Study of Organic Agriculture (1947); Ehrenfried Pfeiffer, Biodynamic Farming and Gardening 26–27 (2nd ed. 1943); Monica M. White, Freedom Farmers: Agricultural Resistance and the Black Freedom Movement (2018).

[10] Econ. Rsch. Serv., U.S. Dep't Agric., Agricultural Resources and Environmental Indicators, 2019, (Daniel Hellerstein, Dennis Vilorio & Marc Ribaudo eds., 2019); L. Snyder, M. Schonbeck, T. Velez & B. Tencer, *2022 National Organic Research Agenda: Outcomes and Recommendations from the 2020 National Organic & Transitioning Farmer Surveys and Focus Groups,* Organic Farming Research Foundation (2022) https://ofrf.org/wp-content/uploads/2022/08/OFRF_National-Organic-Research-Agenda-NORA_2022-report-FINAL.pdf.

Michigan and Ohio, 92 percent of organic farmers planted cover crops, often grass-legume bicultures or more complex mixtures, compared to 61 percent of conventional farmers, who most often used rye alone.[11] Most organic producers use annual or perennial legume cover crops as a source of N for production crops, as discussed in "Nutrient Management in Organic Farming Systems."

Research has shown that crop diversity is essential for soil health and weed management in organic systems. A common organic field crop rotation is corn followed by winter cover, then soybean double cropped with a winter cereal grain, which is overseeded with alfalfa, clover, or legume-grass mix before grain harvest. The perennial crop is grown for 1 to 3 years and can be grazed or hayed. This rotation improves soil health and reduces weed pressure, whereas a 2-year corn-soy rotation leads to deteriorating soil quality and worsening weed pressure, even when all other practices and inputs comply with NOP regulations.[12]

Other strategies that organic producers use to build soil health through crop diversity include:

- Alternating several years' annual crop production with 2 or more years in grass-legume sod, during which soil health can be further enhanced with rotational grazing (Figure 1).
- Intercropping, in which two or more crops with different and complementary nutrient needs, rooting depths, or habits of growth are planted in alternating rows simultaneously.
- Companion planting, in which intercropped species are selected to help one another directly by harboring natural enemies of crop pests, enhancing microclimate (e.g., partial shade or windbreak), or supporting mutually beneficial soil microbiomes.
- Relay planting, in which a cover crop is interplanted into a standing production crop (Figure 2). Cover crops and planting dates are selected for site-specific conditions to allow the cover crop to establish without competing excessively with the production crop.

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[11] E.D. Schoolman & J.G. Arbuckle, *Cover Crops and Specialty Crop Agriculture: Exploring Cover Crop Use among Vegetable and Fruit Growers in Michigan and Ohio,* 77 Journal of Soil and Water Conservation 403 (2022).
[12] C.C. Sheaffer, P. Nickel, D.L. Wyse & D.L. Allan, *Integrated Weed and Soil Management Options for Organic Cropping Systems in Minnesota,* U.S. Dep't Agric. (2007), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0192835").

Figure 1. Elmwood Stock Farm, a crop-livestock organic farm in central Kentucky developed a rotation of three years vegetables with cover crops (left), followed by five years in grass-legume sod under mixed species rotational grazing (right), which restores SOM and other soil health parameters to levels like permanent pasture.[13]

Figure 2. Farmer and author Eliot Coleman developed an 8-year rotation for his organic operation in central Vermont (hardiness zone 4b) that included eight vegetable harvests and seven cover crops.[14] He rigged a multirow push seeder (left) to interplant hardy clovers into vegetable crops at mid-season so that they are established when vegetables are harvested (center) and can cover the ground before winter (right).

Conservation tillage

Organic production of annual vegetable, grain, and row crops generally uses some tillage to facilitate planting and manage weeds, and farmers and researchers continue to develop strategies to minimize associated damage to soil structure and health. While conservation tillage research initially focused on no-till systems that replaced steel with herbicides, most organic farmers in

[13] D. Lin, R.L. McCulley, J.L. Nelson, K.J. Jacobsen & D. Zhang, *Time in Pasture Rotation Alters Soil Microbial Community Composition and Function and Increases Carbon Sequestration Potential in a Temperate Agroecosystem,* 698 Sci. of the Total Env't. (2020) https://doi.org/10.1016/j.scitotenv.2019.134233.

[14] E. Coleman, The New Organic Grower (1989).

the Corn Belt had switched from the moldboard plow to chisel, shallow, or ridge tillage by the end of the 1970s.[15] These practices do less damage to soil life than annual deep plowing.[16]

NOP § 205.203 requires certified organic growers to till with care:

> *"The producer must select and implement tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion."*

Organic producers use several strategies to meet these NOP criteria:

- Modern tools designed to perform shallow, lower-intensity, non-inversion tillage such as the high-speed disk, rotary harrow, and vertical tillage implements.
- Older tools adjusted to reduce tillage depth and intensity, such as light disk harrow or a rotary tiller operated at a lower Power Take Off (PTO) speed.
- Strip, zone, or ridge tillage, which disturbs only a fraction of the field area.
- Rotational no-till, in which cover crops are roller-crimped for no-till cash crop planting, followed by shallow tillage as needed to seed the next cover or cash crop.
- Integrated ecological weed management strategies that reduce the need for cultivation.
- Timely, shallow cultivation with precision tools and optical guidance technology to get the most weed control with the least soil disturbance.

Although continuous no-till may not be practical for organic annual cropping systems, similar percentages (around 39 percent) of organic and conventional producers who participated in the most recent USDA agricultural census reported using some form of conservation tillage.[17] Cropland soils under shallow (less than 6 inches) non-inversion tillage have been found to support nearly twice the soil fungal and bacterial biomass as soils in conventional tillage of deeper (8–10 inches) moldboard plowing followed by disking, whereas continuous no-till enhanced microbial biomass to a much lesser degree.[18] These findings indicate that judicious use of low-intensity, non-inversion tillage with cover crops, diverse rotations, and organic soil amendments is compatible with optimal soil health.

For more information, see the NRCS Guidebook, "Tillage Tools and Practices in Organic Farming Systems: Limiting Soil Disturbance to Build Soil Health in Organic Cropland."

Non-use of synthetics

[15] George Kuepper & Jeff Schahczenski, *Reducing Tillage Intensity in Organic Production Systems,* ATTRA Sustainable Agriculture (Nov. 2020) https://attra.ncat.org/publication/reducing-tillage-intensity-in-organic-systems/.
[16] H. Sun, P. Koal, D. Liu, G. Gerl, R. Schroll, A. Gattinger, R.G. Joergensen & J.C. Munch, *Soil Microbial Community and Microbial Residues Respond Positively to Minimum Tillage under Organic Farming in Southern Germany,* 108 Applied Soil Ecology 16 (2016); S.M. Zuber & M.B. Villamil, *Meta-analysis Approach to Assess Effect of Tillage on Microbial Biomass and Enzyme Activities,* 97 Soil Biology and Biochemistry 176 (2016).
[17] Mallory Krieger & Nate Powell-Palm, *Moldboards and Dust Clouds: Organic Has a Tillage Problem,* The Dirt on Organic Farming, at 15:33 (Jul. 30, 2021) https://www.organicagronomy.org/the-dirt-on-organic-farming.
[18] A. Morugán-Coronado, P. Pérez-Rodríguez, E. Insolia, D. Soto-Gómez, D. Fernández-Calvino & R. Zornoza, *The Impact of Crop Diversification, Tillage and Fertilization Type on Soil Total Microbial, Fungal and Bacterial Abundance: A Worldwide Meta-analysis of Agricultural Sites,* 329 Agric., Ecosystems & Env't 107867 (2022).

NOP § 205.105 excludes the use of most synthetic fertilizers and crop protection chemicals in organic crop and livestock production:

> *"To be sold or labeled as … "organic" … the product must be produced … without the use of synthetic substances and ingredients, except as provided in [the National List of synthetic substances allowed for use in organic crop production, and without the use of] nonsynthetic substances prohibited in [the National List].*

The National List of allowed synthetic substances includes restrictions and criteria for when these materials may be used. Examples include elemental sulfur, hydrogen peroxide, and certain copper compounds (at rates that do not build up excess soil copper) for disease and pest control and micronutrients for a documented soil or crop deficiency. The National List undergoes periodic review by the National Organic Standards Board to determine whether a given synthetic substance is no longer needed for organic production because safe, effective natural alternatives have become available. For example, streptomycin antibiotic for fire blight control was removed from the National List when effective biocontrol agents became available.

The National List also includes a short list of natural materials that are prohibited in organic production because of their toxicity. These include ash from manure burning, arsenic, lead salts, nicotine sulfate, rotenone, and strychnine.

Throughout the history of organic farming, practitioners have avoided synthetic fertilizers, pesticides, herbicides, fungicides, and other inputs out of concern for their potential harm to soil life and health as well as pollinators, natural enemies of pests, wildlife, farmers and farm workers, and consumers. Agrichemicals have long been known to impact beneficial insects, wildlife, aquatic ecosystems, and human health, and recent findings have begun to document their effects on soil life. A review of 400 studies showed that all classes of crop protection chemicals can harm earthworms, micro-arthropods, and other soil invertebrates.[19] Organically managed soils have higher earthworm populations and biomass than soils under conventional management with pesticides.[20]

Use of pesticides and herbicides has been found to alter bacterial, fungal, and nematode communities in cropland soils, often to a greater degree than tillage.[21] Normal use rates of glyphosate and other agrochemicals can reduce the activity of mycorrhizal fungi and other

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[19] T. Gunstone, T. Cornelisse, K. Klein, A. Dubey & N. Donley, *Pesticides and Soil Invertebrates: A Hazard Assessment,* 9 Frontiers in Env't. Sci. (2021), https://doi.org/10.3389/fenvs.2021.643847.

[20] C. Pelosi, S. Barot, Y. Capowiez, M. Hedde & F. Vandenbulcke, *Pesticides and Earthworms. A Review,* 34 Agronomy for Sustainable Dev. 199 (2014).

[21] J. Puissant, C. Villenave, C. Chauvin, C. Plassard, E. Blanchart & J. Trap, *Quantification of the Global Impact of Agricultural Practices on Soil Nematodes: A Meta-analysis,* 161 Soil Biology and Biochemistry 108383 (2021), https://doi.org/10.1016/j.soilbio.2021.108383; T. Vahter, SK Sepp, A. Astover, A. Helm, T. Kikas, S. Liu, J. Oja, M. Öpik, P. Penu, M. Vasar, E. Veromann, M. Zobel & I. Hiiesalu, *Landscapes, Management Practices and their Interactions Shape Soil Fungal Diversity in Arable Fields – Evidence from a Nationwide Farmers' Network,* 168 Soil Biology and Biochemistry (2022), https://doi.org/10.1016/j.soilbio.2022.108652; F. Walder, M.W. Schmid, J. Riedo, A.Y. Valzano-Held, S. Banerjee, L. Büchi, T.D. Bucheli & M.G.A. van der Heijden, *Soil Microbiome Signatures are Associated with Pesticide Residues in Arable Landscapes,* 174 Soil Biology and Biochemistry (2022), https://doi.org/10.1016/j.soilbio.2022.108830.

beneficial microbes.[22] In contrast, organic carrot and lettuce suffer less disease because soils not exposed to synthetic inputs support a more disease-suppressive microbiome.[23]

Moderate to high rates of soluble Nitrogen-Phosphorus-Potassium (NPK) fertilizers also seem to disrupt soil microbiome function, resulting in reductions in SOM and soil organic N reserves despite increased crop and residue biomass,[24] while global meta-analyses have confirmed that using organic nutrient sources instead of soluble fertilizers can double total soil microbial biomass and gradually build SOM levels.[25]

These findings suggest that organic systems that exclude the use of most synthetic fertilizers and crop protection chemicals can accrue the following soil-related benefits:

- Healthier and more complete community of soil life.
- Enhanced nutrient cycling and crop nutrition and reduced need for fertilizers.
- More disease-suppressive soils and disease-resistant crops.
- Higher SOM.

Organic practices and NOP criteria for nutrient, pest, weed, and disease management are discussed in greater detail in this technical note under "Nutrient Management in Organic Farming Systems" and "Weed, Pest, and Disease Management in Organic Farming Systems."

Organic Farming and Climate Change

As climate change impacts on agriculture, vulnerable communities, infrastructure, and national economies become ever more intense, society is turning to farmers, ranchers, and agricultural professionals for part of the solution. Farmers can help through management strategies that:

- Sequester carbon in the soil.
- Reduce greenhouse gas (GHG) emissions.
- Make our food system more resilient to the impacts of climate disruption.

Conservation practices that build soil organic matter (SOM) also sequester carbon (C). SOM is about 50 percent soil organic carbon (SOC), and the ultimate source of all SOC is plant photosynthesis. Plants donate 10–40 percent of their photosynthetic product to the soil through

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[22] M. Druille, M.N. Cabello, M. Omacini & R.A. Golluscio, *Glyphosate Reduces Spore Viability and Root Colonization of Arbuscular Mycorrhizal Fungi,* 64 Applied Soil Ecology 99 (2013) https://doi.org/10.1016/j.apsoil.2012.10.007; Kendra Klein, *Pesticides and Soil Health,* Friends of the Earth (2019), https://foe.org/wp-content/uploads/2019/08/PecticidesSoilHealth_Final-1.pdf.

[23] Sahar Abdelrazek, Carrot Endophytes: Diversity, Ecology and Function (2018) (Ph.D. dissertation, Purdue University) (on file with Purdue e-Pubs); Ariena H.C. van Bruggen, Isolde M. Francis & Randy Krag, *The Vicious Cycle of Lettuce Corky Root Disease: Effects of Farming System, Nitrogen Fertilizer and Herbicide,* 388 Plant and Soil 119 (2015).

[24] S.A. Khan, R.L. Mulvaney, T.R. Ellsworth & C.W. Boast, *The Myth of Nitrogen Fertilization for Soil Carbon Sequestration,* 36 J. Env't. Quality 1821 (2007); R.L. Mulvaney, S.A. Khan & T.R. Ellsworth, *Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production,* 38 J. Env't. Quality 2295 (2009).

[25] Morugán-Coronado et al., *supra* note 18; see also M.D. Young, G.H. Ros & W. de Vries, *Impacts of Agronomic Measures on Crop, Soil, and Environmental Indicators: A Review and Synthesis of Meta-analysis,* 319 Agric., Ecosystems & Env't. (2022), https://doi.org/10.1016/j.agee.2021.107551.

root exudates and add more carbon to the surface when they drop their leaves or die. As soil microbes feed and grow on this plant-derived carbon, they turn part of it into stable SOC.

Microbes also regulate GHG emissions from agricultural activities by modulating soil nitrogen (N) cycling and nitrous oxide (N_2O) formation, enteric methane (CH_4) production in ruminant livestock, and manure decomposition. In terms of global warming potential over a 100-year period after it enters the atmosphere, N_2O is about 300 times as potent as CO_2, and CH_4 is about 25 times as potent. Ongoing research seeks to identify best management practices for minimizing these emissions while sustaining soil fertility and agricultural production.

Finally, healthy soils enhance crop and livestock resilience to weather extremes, pests, diseases, and other stressors. Thus, the soil health practices discussed in the previous section will help mitigate the impacts of climate disruption on the farm operation.

The NOP regulations do not directly address climate mitigation and resilience; however, several organic conservation activities can have significant climate benefits. These activities and their relationship with NRCS practice standards are shown in Table 3.

Table 3. Organic and NRCS conservation activities that contribute to climate mitigation.

Organic Activity	CPS and other NRCS Activities	Potential Climate Impacts
Composting; use of compost and other organic residues	Composting Facility (317) Soil Carbon Amendment (336) Four Principles of Soil Health	Build SOC, divert organic residues from CH_4-emitting waste streams.
Multiple practices to build SOM	Conservation Crop Rotation (328) Cover Crop (340) Reduced Till (345) Soil C Amendment (336)	Build SOC and resilience; complements and amplifies stacked practices
Biologically based nutrient management	Nutrient Management (590) Soil C Amendment (336), esp. biochar	Minimizing concentrated N and P inputs and use of biochar mitigate N_2O. (Research ongoing.)
Grazing management	Prescribed grazing (528) Pasture and Hay Planting (512) Silvopasture (381)	Sequester C in soil and plant biomass, reduce manure and enteric GHG.
Non-use of Synthetics	Nutrient Management (590) Pest Management Conservation System (595)	Protect soil life involved in C and N cycling, reduce input embodied CO_2.

Agricultural GHG emissions, climate change, and the National Organic Standards

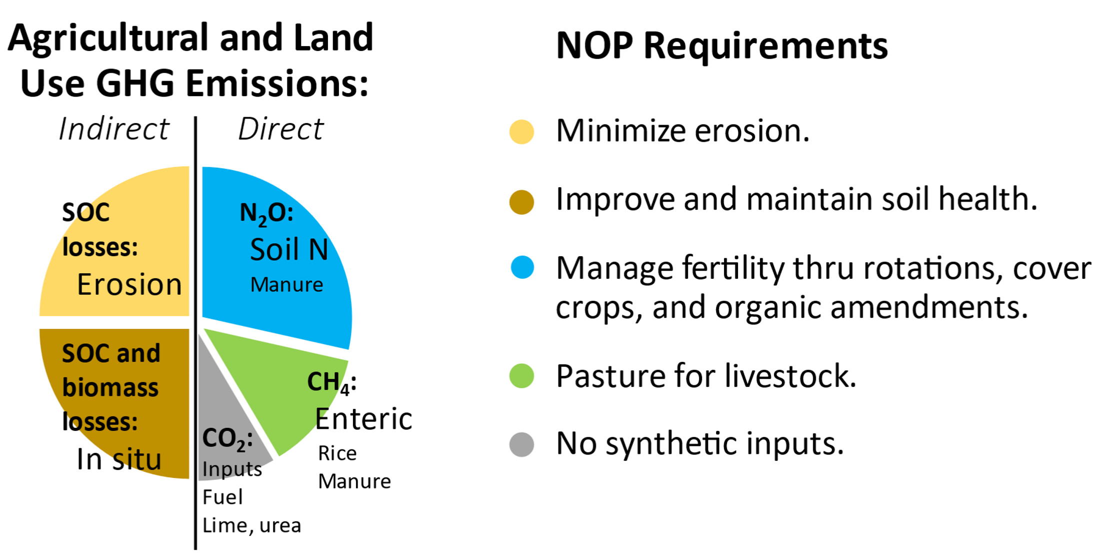
Agriculture is one of many sectors contributing to the total GHG emissions in the United States. In 2019, direct agricultural GHG emissions (defined as GHG from cropland, grazing land, and livestock facilities including manure storage) accounted for 9.6 percent of the total (US EPA, 2021). Of the direct agricultural GHG, 54 percent was N_2O from fertilized, manured, or green-manured soils, 28 percent was enteric CH_4 from ruminant livestock, 14 percent was N_2O and

CH_4 from lagoons and other manure storage, and the remaining 4 percent were CH_4 from flooded rice fields and CO_2 emissions from field burning and field-applied lime and urea.

These figures do not include fossil fuel for farm machinery or embodied energy in fertilizers, pesticides, and other inputs. The global warming potential of CO_2 emissions from these sources has been estimated as only one-sixth as large as the direct N_2O and CH_4 emissions[26] and would increase the agricultural GHG footprint to about 11 percent of the U.S. total. When agricultural GHG emissions from all these sources are considered, the first, second, and third largest sources in global warming potential are N_2O, CH_4, and CO_2 respectively (Figure 3).

When net losses in SOC and plant biomass carbon resulting from agricultural and land use activities are considered, the global GHG footprint of agriculture doubles to roughly 25 percent of total human-caused GHG emissions.[27] About half of this loss results from wind and water erosion, which disproportionately removes SOM, exposing it to oxidation or (when eroded sediment is submerged in water bodies) conversion into CH_4; in other words, about 6 percent of total GHG emissions can be attributed to soil erosion.[28] The other half results from *in-situ* soil degradation caused by excessive tillage, bare fallow, excessive nutrient and pesticide applications, and clearing of forest and other vegetation.

Most organic farmers strive to minimize the net GHG footprint of their operations in alignment with their environmental values and those of their customers. Although the NOP regulations do not include a climate stewardship standard per se, several regulations are related to mitigating the major sources of agricultural GHG emissions (Figure 3).



[26] L. Carpenter-Boggs, *Greenhouse Gases and Agriculture: Where does Organic Farming Fit Webinar,* eOrganics (2010) https://eorganic.org/node/5617.
[27] Intergovernmental Panel on Climate Change, AR5 Climate Change 2014: Mitigation of Climate Change, ch. 11 at 811 and Annex II at 1281 (2014) https://www.ipcc.ch/report/ar5/wg3/; Ray R. Weil & Nyle C. Brady, The Nature and Properties of Soils (15th ed. 2017).
[28] R. Lal, *Soil Erosion and the Global Carbon Budget,* 29 Env't. Int'l. 437 (2003).

Figure 3. Direct and indirect greenhouse gas (GHG) emissions from agricultural operations and land use and how NOP regulations provide guidance on reducing the net GHG footprint of an organic operation.

Can organic farming help mitigate climate change?

Organic farming systems contribute to GHG mitigation in several ways.

- Building SOM sequesters carbon.
- Non-use of synthetic agrochemicals reduces embodied energy CO_2 emissions and protects soil microbes involved in SOC and N cycling.[29]
- Pasture-based livestock systems (required by NOP) mitigates manure GHG emissions by improving manure distribution and reducing the amount of manure that must be stored.
- On-farm composting of farm-generated manure emits less GHG than liquid storage (lagoons or pits) or unmanaged dry stockpiles.
- Rotational grazing sequesters SOC in pasture soils and provides high-quality forage that can reduce ruminant enteric CH_4 by 30 percent.[30]

Organic farmers face several challenges in minimizing the net GHG footprint of the operation.

- Tillage and cultivation contribute to oxidation of SOC.
- High soil P levels from manure and compost can inhibit mycorrhizal fungi, which play a key role in SOC sequestration.[31]
- Relying on concentrated organic fertilizers like poultry litter to maintain yields can compromise SOC accrual and N cycling efficiency.[32]
- While organic nutrient sources generally build more SOC, reduce N leaching by 43 percent, and cut ammonia (NH_3) emissions by 52 percent compared to soluble fertilizers, they can emit up to 25 percent more N_2O.[33]

Soil carbon sequestration and imported carbon in organic farming systems

Organically managed soils contained 13 percent and 19 percent more SOC per acre than their conventional counterparts in national and global multisite comparisons, respectively.[34] Long-

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[29] A. Sharma, M. Reeves & C. Washburn, *Pesticides and Climate Change: A Vicious Cycle,* Pesticide Action Network (2023), https://www.panna.org/resources/pesticides-and-climate-change-a-vicious-cycle/.
[30] P.L. Stanley, J.E. Rowntree, D.K. Beede, M.S. DeLonge & M.W. Hamm, *Impacts of Soil Carbon Sequestration on Life Cycle Greenhouse Gas Emissions in Midwestern USA Beef Finishing Systems,* 162 Agric. Sys. 249 (2018); T. Wang, W.R. Teague, S.C. Park & S. Bevers, *GHG Mitigation Potential of Different Grazing Strategies in the United States Southern Great Plains,* 7 Sustainability 13500–13521 (2015).
[31] C. Hamel, *Impact of Arbuscular Mycorrhizal Fungi on N and P Cycling in the Root Zone,* 84 Can. J. Soil Sci. 383 (2004); S. Hu, C. Reberg-Horton, M. Schroeder-Moreno, Y. Cardoza, J. Grossman, W. Robarge & W. Eveman, *Assessing the Greenhouse Gas Mitigation Potential of Organic Systems in the Southeast,* U.S. Dep't Agric. (2016), https://portal.nifa.usda.gov/enterprise-search/ (search for "0230561").
[32] Bhowmik et al., *Use of Biological Indicators of Soil Health to Estimate Reactive Nitrogen Dynamics in Long-Term Organic Vegetable and Pasture Systems,* 103 Soil Biology and Biochemistry 308, (2016); Bhowmik et al., *Potential Carbon Sequestration and Nitrogen Cycling in Long-Term Organic Management Systems,* 32 Renewable Agric. and Food Sys. 498, (2017).
[33] Young et al., *supra* note 25.
[34] E.A. Ghabbour, G. Davies, T. Misiewicz, R.A. Alami, E.M. Askounis, N.P. Cuozzo, A.J. Filice, J.M. Haskell, A.K. Moy, A.C. Roach & J. Shade, *National Comparison of the Total and Sequestered Organic Matter Contents of*

term farming systems trials have shown that organic rotations accrue about 400 lb/ac more SOC per year than conventional rotations.[35] A recent review of 15 different meta-analyses found that total SOC stocks of organically fertilized soils increased about 1.1 percent per year compared to soils receiving only soluble fertilizers.[36] In a soil containing 25,000 lb SOC per acre (about 2.5 percent SOM), a 1.1 percent annual increase would represent a gain of 275 lb SOC/ac annually.

Many organic farms apply compost or other organic amendments from off-farm sources to build SOC and soil health as outlined in CPS 336 Soil Carbon Amendment. The proportion of SOC accrual in organic systems that is imported rather than sequestered *in situ* has been estimated at 40 percent.[37] The net climate impact of importing soil carbon amendments depends on the source.

For example, importing residues such as manure, tree leaves, yard trimmings, or food scraps from lagoons or landfills into composting or direct application to agricultural fields can yield a large climate benefit. However, removing organic residues or plant biomass from agricultural fields or natural areas to make soil amendments for use elsewhere is a zero-sum game at best and can deplete SOC in the place where the biomass was taken.

Most organic farmers and composting enterprises use feedstocks that would otherwise go to waste in climate-damaging ways.

Stability of soil carbon and the impacts of tillage and other management practices

Plant root exudates play a major role in SOC sequestration. As soil microbes feed on the sugars and other organic substances in root exudates and root residues, they convert a substantial fraction of these materials into mineral-associated organic matter (MAOM), which is deposited throughout the plant's rooting depth and has a residence time of 1,000 years or longer.[38] Cropping systems that maximize duration of living cover and living root and include deep-rooted crops enhance MAOM formation. Prescott et al. (2021) identified three strategies to build MAOM.

- Avoid excess N and P. Providing these inputs at rates slightly below the optimum for aboveground growth enhances root growth, root exudation, microbial activity, and

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Conventional and Organic Farm Soils, 146 Advances in Agronomy 1 (2017); M. Lori, S. Symnaczik, P. Mäder, G. De Deyn & A. Gattinger, *Organic Farming Enhances Soil Microbial Abundance and Activity—A Meta-analysis and Meta-regression,* PLOS ONE (Jul. 12, 2017), https://doi.org/10.1371/journal.pone.0180442.

[35] M.A. Cavigelli, J.R. Teasdale & J.T. Spargo, *Increasing Crop Rotation Diversity Improves Agronomic, Economic, and Environmental Performance of Organic Grain Cropping Systems at the USDA-ARS Beltsville Farming Systems Project,* 12 Crop Mgmt. 1 (2013); K. Delate, C. Cambardella, C. Chase & R. Turnbull, *A Review of Long-Term Organic Comparison Trials in the U.S.,* 4 Sustainable Agric. Rsch. 5 (2015); A. Gattinger, A. Muller, M. Haeni, C. Skinner, A. Fliessbach, N. Buchmann, P. Mäder, M. Stolze, P. Smith, N.E. Scialabba & U. Niggli, *Enhanced Top Soil Carbon Stocks under Organic Farming,* 109 Proceedings of the National Academy of Sciences 18826 (2012).

[36] Young et al., *supra* note 25.

[37] Gattinger et al., *supra* note 35.

[38] K.A. Dynarski, D.A. Bossio & K. Scow, *Dynamic Stability of Soil Carbon: Reassessing the "Permanence" of Soil Carbon Sequestration,* 8 Frontiers in Env't Sci. (2020), https://doi.org/10.3389/fenvs.2020.514701; S. Grandy & C. Kallenbach, *Increased Microbial Efficiency and Growth Drive Soil Organic Matter Increases in Organic Cropping Systems,* Organic Agric. Rsch. Symp. (February 26, 2015), https://eorganic.info/node/12972; C.E. Prescott, Y. Rui, M.F. Cotrufo & S.J. Grayston, *Managing Plant Surplus Carbon to Generate Soil Organic Matter in Regenerative Agriculture,* 76 J. Soil & Water Conservation 99A (2021).

MAOM formation without affecting yield, whereas ample N and P reduces root growth and exudation, limiting SOC sequestration.

- Include legumes in the rotation. Unlike soluble fertilizers, the N-rich root exudates of legumes enhances microbial activity and MAOM formation.

- In pastures, maintain grass during the portion of the growth phase in which leaves generate surplus carbon. Harnessing surplus plant C to enhance SOM regeneration might also be achieved by managing grazing times in perennial pastures. In unfertilized pastures, plants probably generate surplus photosynthate during the later portion of the active growth phase, when leaf biomass has recovered, and photosynthesis rates are high.

SOC can also become physically protected within soil aggregates. Continuous no-till allows about 500 lb SOC/ac per yr to accumulate in aggregates near the soil surface.[39] However, much of this SOC can be lost through a single tillage pass, and most no-till farmers must till at least once every few years to deal with creeping perennial weeds and other weeds that have evolved herbicide resistance.[40] The carbon in MAOM is much less susceptible to rapid oxidation from a single tillage operation, especially shallow tillage that leaves most of the soil profile undisturbed. Higher soil microbial biomass under shallow noninversion tillage than either moldboard plowing or continuous no-till[41] suggests that shallow tillage is compatible with microbially driven MAOM formation.

Soil respiration and soil health: the paradox of soil CO_2 emissions

Some soil labs now offer a soil respiration test as an estimate of soil biological activity, which is generally considered an index of overall soil health. Yet when estimating the farm's net climate impact, CO_2 emissions from the soil are on the debit side of a farm's GHG balance sheet. CPS 329 Residue and Tillage Management – No Till and CPS 345 Residue and Tillage Management – Reduced Till include strategies for minimizing CO_2 emissions from soil. This apparent contradiction can confuse farmers and conservation professionals trying to develop a climate-friendly strategy.

When soil biological activity increases, so does respiration and, therefore, soil CO_2 emissions. However, this does not necessarily indicate a net loss of SOC or a net increase in GHG emissions. Soil health practices such as cover crops, diverse rotations, and organic amendments enhance microbial growth and microbial processing of organic residues into SOC as well as microbial respiration.[42] Thus, soil test biological activity assessed by a simple 3-day soil

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[39] T.O. West & W.M. Post, *Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation,* 66 Soil Sci. Soc. Am. J. 1930 (2002).

[40] A.S. Grandy, G.P. Robertson & K.D. Thelen, *Do Productivity and Environmental Trade-offs Justify Periodically Cultivating No-till Cropping Systems?*, 98 Agron. J. 1377-1383 (2006); D. Kane, *Carbon Sequestration Potential on Agricultural Lands: A Review of Current Science and Available Practices,* National Sustainable Agriculture Coalition (November 2015), https://sustainableagriculture.net/wp-content/uploads/2015/12/Soil_C_review_Kane_Dec_4-final-v4.pdf.

[41] Morugán-Coronado et al., *supra* note 18.

[42] Lori et al., *supra* note 34; see also Hurisso et al., *supra* note 5.

respiration test (which measures CO_2 emission) is directly related to greater SOC accrual and other soil health parameters.[43]

Soil CO_2 emissions can also increase due to intensive tillage, prolonged fallow, or excessive soluble N applications.[44] These stresses cause a burst of microbial maintenance respiration while reducing microbial growth and SOC accrual, resulting in a net loss of soil carbon.

Soil nitrogen cycling and nitrous oxide emissions in organic systems

The powerful greenhouse gas nitrous oxide (N_2O) forms in agricultural soils through the microbially driven process of denitrification. Soil conditions that promote denitrification include high levels of soluble N, abundant decomposable organic carbon, high microbial activity, and reduced oxygen levels resulting from high soil moisture levels or soil compaction. When the soil pore space is about 80 percent water-filled, oxygen levels are ideal for N_2O formation, whereas denitrification under completely saturated, anaerobic conditions (e.g., rice paddy) results in mostly elemental N_2 gas, although other anaerobic processes lead to CH_4 emissions. Well-aerated soil at or below field capacity (about 50 percent water-filled pore space) does not support denitrification.

Soil N_2O emissions are difficult to predict and control since they typically occur in brief intense bursts after heavy rainfalls or snowmelt creates wet soil conditions. Annual total N_2O emissions have been shown to soar exponentially as the supply of plant-available N rises beyond crop demand, regardless of whether the N comes from soluble fertilizer or organic sources.[45] Thus, N management plays a critical role in mitigating this GHG.

The challenge for organic farmers is that building healthy soil provides two of the ingredients for N_2O emissions: high biological activity and ample decomposable organic carbon (organic amendments, root exudates, cover crop residues, and active SOM). Organic farmers often use higher-analysis organic N sources like poultry litter, feather meal, or an all-legume green manure crop to support production of heavy feeders like corn or broccoli, and some apply manure just before tilling in the green manure. An untimely heavy rainfall event after a legume and manure plowdown creates perfect conditions for N_2O emissions, and seasonal total N_2O emissions can reach 10–27 lb N/ac.[46] These emissions negate some 1,300–3,500 lb/ac SOC sequestration.

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[43] A.J. Franzluebbers, *Short-Term C Mineralization (aka the Flush of CO2) as an Indicator of Soil Biological Health,* CABI Reviews (2018), https://doi.org/10.1079/PAVSNNR201813017.

[44] R.P. Dick, *A Review: Long-Term Effects of Agricultural Systems on Soil Biochemical and Microbial Parameters,* 40 Agric., Ecosystems, and Env't. 25 (1992); M.F. Fauci & R.P. Dick, *Soil Microbial Dynamics: Short- and Long-Term Effects of Inorganic and Organic Nitrogen,* 58 Soil Sci. Soc. Am. J. 801 (1994); see also Zuber et al., *supra* note 16, and Lori et al., *supra* note 34.

[45] B.W. Davis, S.B. Mirsky, B.A. Needelman, M.A. Cavigelli & S.A. Yarwooda, *Nitrous Oxide Emissions Increase Exponentially with Organic N Rate from Cover Crops and Applied Poultry Litter,* 272 Agric., Ecosystems & Env't. 165 (2019); A.J. Eagle, L.P. Olander, K.L. Locklier, J.B. Heffernan & E.S. Bernhardt, *Fertilizer Management and Environmental Factors Drive N2O and NO3 Losses in Corn: A Meta-analysis,* 81 Soil Sci. Soc. Am. J. 1191 (2017).

[46] D.G. Baas, G.P. Robertson, S.R. Miller & N. Millar, *Effect of Cover Crops on Nitrous Oxide Emissions, Nitrogen Availability & Carbon Accumulation in Organic vs. Conventionally Managed Systems,* U.S. Dep't. Agric. (2015), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0226882"); Z. Han, M.T. Walter & L.E. Drinkwater, *Impact of Cover Cropping and Landscape Positions on Nitrous Oxide Emissions in Northeastern US*

However, research has identified more climate-friendly N management options for organic systems. Organic amendments with a moderate C:N ratio such as finished compost (C:N approx. 20:1) build more SOC and promote more efficient N cycling than more concentrated organic nutrient sources such as poultry litter or bat guano (C:N approx. 7). In California, organic tomatoes fields amended with compost sustained top yields while soil soluble N levels remained low enough to minimize N_2O emissions.[47] A research team in maritime Washington State compared organic vegetable rotations amended with poultry litter (1.8–2.7 t/ac per yr, C:N approx. 7) versus compost from mixed plant residues and manure (6–8 t/ac-yr, C:N approx. 20) which provided equivalent total amounts of N.[48] After 11 years, the composted-amended soil showed:

- 43 percent higher total SOC per acre.
- 19 percent greater capacity to mineralize plant-available N from SOM.
- Greater capacity to immobilize excess soluble N and limit N_2O emissions.
- Similar crop yields from the two N sources.

Biochar, a charcoal-like soil amendment created by pyrolysis (heating with restricted oxygen) of organic residues, has shown promise for mitigating N_2O emissions while improving both SOC sequestration and crop yields. Meta-analyses indicate that biochar reduces N_2O emissions by an average of 40 percent while improving yields 12 percent.[49]

Healthy soils under long-term organic management can meet most of a crop's N need through SOM mineralization, thus greatly reducing or eliminating the need for applied N.[50] The NRCS COMET Planner tool estimates that replacing all applied fertilizer N with soil-derived N can reduce net GHG emissions by 3,965 lb CO_2-equivalents/acre per year, compared to 440 lb CO_2-eq/acre-year for CPS 590 Nutrient Management implemented with conventional fertilizers.[51]

Agroecosystems, 245 Agric., Ecosystems & Env't. 124 (2017); A.R. Kemanian, *Smart Tillage to Reduce N2O Emission from Organic Agriculture* U.S. Dep't. Agric. (2021), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1020521"); C. Li, W. Salas, & J. Muramoto, *Process Based Models for Optimizing N Management in California Cropping Systems: Application of DNDC Model for Nutrient Management for Organic Broccoli Production,* Cal. Soil and Plant Conf., 92 (Feb. 2009), http://ucanr.edu/sites/calasa/files/319.pdf; see also Davis et al., *supra* note 45.

[47] Bowles et al., *supra* note 5.

[48] Bhowmik et al., *Use of Biological Indicators of Soil Health to Estimate Reactive Nitrogen Dynamics in Long-Term Organic Vegetable and Pasture Systems,* 103 Soil Biology and Biochemistry 308 (2016); Bhowmik et al., *Potential Carbon Sequestration and Nitrogen Cycling in Long-Term Organic Management Systems,* 32 Renewable Agric. and Food Sys. 498 (2017); C.G. Cogger, M. Ostrom, K. Painter, A. Kennedy, A. Fortuna, R. Alldredge, A. Bary, T. Miller, D. Collins, J. Goldberger, A. Antonelli & B. Cha, *Designing Production Strategies for Stewardship and Profits on Fresh Market Organic Farms,* U.S. Dep't. Agric. (2013) https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0213730").

[49] Young et al., *supra* note 25.

[50] A.J. Franzluebbers, *Soil-Test Biological Activity with the Flush of CO2: III. Corn Yield Responses to Applied Nitrogen,* 82 Soil Sci. Soc. of Am. J. 708 (2018); A.J. Franzluebbers, S. Pehim-Limbu & M.H. Poore, *Soil-Test Biological Activity with the Flush of CO2: IV. Fall-Stockpiled Tall Fescue Yield Response to Applied Nitrogen,* 110 Agronomy J. 2033 (2018); D. Robb & G. Zehnder, *Weeds, Nitrogen, and Yield: Measuring the Effectiveness of an Organic No-Till System,* Sustainable Agric. Rsch. Educ. (2016), https://projects.sare.org/project-reports/gs13-126/.

[51] Léopold Biardeau, Rebecca Crebbin-Coates, Ritt Keerati, Sara Litke & Hortencia Rodríguez, *Soil Health and Carbon Sequestration in US Croplands: A Policy Analysis,* Univ. Cal. Berkeley (2016), https://food.berkeley.edu/wp-content/uploads/2016/05/GSPPCarbon_03052016_FINAL.pdf.

For more information on organic N management, see Nutrient Management in Organic Farming Systems.

Priority Organic practices for C sequestration, GHG mitigation, and climate resilience

- Apply the four principles of soil health: keep soil covered, maintain living root, maximize biodiversity, and minimize disturbance.
- Stop erosion, which selectively steals SOC and converts it to CO_2 and CH_4. Keep steeper or otherwise erodible areas in permanent vegetative cover.
- Combine vegetative practices (cover crops, rotation, etc.) with organic amendments such as compost for synergistic effect on SOC.
- Use organic amendments and cover crop mixes with a moderate C:N ratio.
- Avoid soil nutrient excesses, especially N and P (see Nutrient Management).
- Include legumes in the rotation in balance with grasses and other forbs.
- Integrate perennials into the production system.
- Time rotational grazing to occur late in the rapid growth phase of the forage.

Nutrient Management in Organic Farming Systems

Organic farmers seek to meet crop nutrient needs primarily by building and maintaining healthy, living soils that can provide plant-available nitrogen (N), phosphorus (P), and other nutrients through microbial mineralization of organic residues and active soil organic matter (SOM), mobilization of essential elements in soil minerals, and other biologically mediated processes. Cover crops, diverse rotations, compost, and other organic soil amendments maintain the soil's capacity to feed the crop and replenish nutrients removed in harvest. These practices also build stable mineral-associated organic matter (MAOM), which contributes to the soil's cation exchange capacity, that is, its ability to hold positively charged (cation) nutrients like potassium (K), calcium (Ca), magnesium (Mg), and some micronutrients in plant-available form.

In addition to this "feed the soil" approach, organic farmers sustain crop yields by using more concentrated organic fertilizers such as poultry litter, feather meal, blood meal, fish emulsion, and plant-based meals (soy, alfalfa, seaweed) to feed the crop as needed. NOP-allowed mineral amendments (limestone, elemental sulfur) are used to adjust pH and address documented soil or plant nutrient deficiencies. These inputs are most needed during the first few years after a field transitions from conventional to organic management or neglected or depleted land is brought into organic production. As soil health improves, crop needs for concentrated supplements decrease, and some organic farmers gradually phase them out altogether.

Most organic producers pay close attention to *all* nutrients essential to plants, livestock, and humans. In addition to N, P, and K, these include Ca, Mg, sulfur (S), sodium (Na), and the micronutrients boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), molybdenum (Mo), nickel (Ni), cobalt (Co), and selenium (Se). Several of these micronutrients play essential roles in plant and microbial N and P metabolism and N fixation; thus, ensuring sufficient micronutrient levels contributes to N and P use efficiency, crop yield, and water quality.

Some organic producers create a complete nutrient budget that accounts for all nutrient inputs and removals as outlined in the general criteria for CPS 590 Nutrient Management. Others develop a fertility plan based on locally available resources, direct observations of crop responses, and periodic soil testing to monitor trends in nutrient levels. Because standard soil tests may not precisely reflect crop nutritional status, some farmers conduct complete foliar nutrient analyses to verify soil test findings and pinpoint nutrient needs.

The Base Cation Saturation Ratio is an alternative nutrient management system, first developed in the mid-20th century, that focuses on balancing the soil cations (Ca, Mg, K, and Na) for improved soil, crop, and livestock health. Research has not shown a clear advantage for this system over a strategy of maintaining nutrient levels.

More recently, proponents of nutrient-dense farming seek to build soil micronutrients and microbiomes to levels thought to optimize the nutritional quality of farm products. Unlike USDA Certified Organic, market claims like "nutrient-dense" have no legal definition; however, the potential for these methods to enhance both soil heath and the nutritional value of organic products merits further research.

Table 4 summarizes organic nutrient management practices in relation to NRCS practices.

Table 4. Organic nutrient management activities and criteria in relation to existing NRCS practices.

Organic Conservation Activity	Complete Coverage in Existing CPS	Partial Coverage in Existing CPS	Topics in Existing CPS	New Criteria for Organic Nutrient Management
Biologically based nutrient management	No	Nutrient Management (590)	Nutrient budgeting, 4Rs of nutrient management, criteria for N and P	Plant- & animal-based fertilizers, <50% of N from concentrated sources, avoid surplus P
Advanced nutrient management	No	Nutrient Mgmt. (590) Considerations section	Adaptive nutrient management, legumes for N, soil health management system	Research ongoing to maximize soil-derived N and minimize applied N
Crop rotation	No	Conservation Crop Rotation (328)	Rotation for soil, water quality, and pest management	Rotation to balance nutrient needs and fix N
Non-use of synthetics	No	Nutrient Management (590)	Criteria for compost and manure use	NOP-allowed and -prohibited nutrient inputs

Nutrient sources for USDA-certified organic systems

NOP §§ 205.203, 205.602, 205.603, and 205.601 provides the following roadmap for organic nutrient management (see full regulations for complete details):

> *"The producer must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials … including:*
> > *"Raw animal manure [see page 7 for required application-to-harvest intervals] …*
> > *"Composted … materials [see page 7 for NOP composting criteria] …*
> > *"Uncomposted plant materials.*
>
> *"A producer may manage crop nutrients and soil fertility … by applying:*
> > *"A crop nutrient or soil amendment included on the National List of synthetic substances allowed for use in organic crop production.*
> > *"A mined substance of low solubility.*
> > *"A mined substance of high solubility [not included in] the National List of nonsynthetic materials prohibited for crop production."*
> > > *"Sodium nitrate … use is restricted to no more than 20% of the crop's total nitrogen requirement."*
> >
> > *"Ash obtained from the burning … plant or animal material[s] except [as noted below].*
> > *"A plant or animal material that has been chemically altered by a manufacturing process … [and] is included on the National List of [allowed] synthetic substances.*
>
> *"The producer must manage [the above-listed] materials to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances.*
>
> *"The producer must not use:*
> > *"Any fertilizer or compost … that contains a [prohibited] synthetic substance.*
> > *"Sewage sludge (biosolids) …"*
> > *"Ash from manure burning."*
> > *"Burning as a means of disposal for crop residues … burning may be used to suppress the spread of disease or to stimulate seed germination."*
>
> *"Synthetic substances allowed for use … as plant or soil amendments:*
> > *"Aquatic plant extracts …*
> > *"Elemental sulfur (S).*
> > *"Humic acids – naturally occurring extracts, water [or] alkali extracts …*
> > *"Lignin sulfonate – chelating agent, dust suppressant.*
> > *"Magnesium sulfate [for] documented soil deficiency.*
> > *"Micronutrients [for deficiencies] documented by soil or tissue testing:*
> > > *"Soluble boron products.*
> > > *"Sulfates, carbonates, oxides, or silicates of zinc, copper, iron, manganese, molybdenum, selenium, and cobalt. [Nitrates or chlorides are not allowed.]*
> >
> > *"Liquid fish [or squid] products … pH adjusted [to 3.5] with phosphoric, sulfuric, or citric acid."*

Table 5 shows some examples of NOP-allowed nutrient sources commonly used by organic producers. It is not an exhaustive list, as vendors offer a wide range of NOP-allowed fertilizer blends from which producers can choose the best fit for their crop, soil type, and soil test report.

Table 5. Some NOP-allowed nutrient sources and pH amendments for organic crops.

Nutrient source	**NOP category**	**%N**	**%P_2O5**	**%K_2O**	**Other Nutrients**
Manure	Animal material	Varies	Varies	Varies	All[52]
Compost	Plant & animal materials	Varies	Varies	Varies	All[51]
Tree leaves	Plant material	Varies low	Varies low	Varies low	All, esp. micro[51]
Seaweed meal	Plant material	1	0	2	All, esp. micro[51]
Poultry litter fertilizer	Plant & animal materials	5	3	4	All[51]
Alfalfa meal	Plant material	3	0.5	3	All[51]
Fish-seaweed liquid	Allowed synthetic[53]	2	3	1	All, esp. micro[51]
Feather meal	Animal material	13	0	0	Insignificant
Sodium nitrate	Mined, high solubility[54]	15	0	2	Insignificant
Rock phosphate	Mined, low solubility	0	20–30	0	Ca: approx. 30
Potassium sulfate	Mined, high solubility	0	0	50	S: 17
Langbeinite (K-mag)	Mined, high solubility	0	0	22	Mg: 11; S: 22
Azomite (volcanic)	Mined, low solubility	0	0	0	Micronutrients
Solubor	Allowed synthetic[55]	0	0	0	B: 20.5
Copper sulfate	Allowed synthetic[54]	0	0	0	Cu: 25.5; S: 12.5
Zinc sulfate	Allowed synthetic[54]	0	0	0	Zn: 35.5; S: 17.5
Calcitic limestone	Mined, low solubility	0	0	0	Ca: 35
Dolomitic limestone	Mined, low solubility	0	0	0	Ca: 23; Mg: 9.5
Elemental sulfur	Allowed synthetic	0	0	0	S: 90

Organic nutrient management opportunities and challenges

Because organic systems use soil biological processes and organic and natural mineral amendments instead of soluble fertilizers to meet crop nutritional needs, they require some modifications to conventional nutrient management planning. While CPS 590 Nutrient Management provides a useful overall framework for nutrient budgeting and management, CPS Organic Management provides additional criteria and considerations to help organic producers

[52] Most plant- and animal-derived materials contain varying amounts of S, Ca, Mg, and essential plant micronutrients. Tree leaves and seaweed products are good sources of micronutrients.
[53] Considered a synthetic because of the acid used to stabilize the product.
[54] Limited to 20 percent of total crop N requirement.
[55] For deficiencies documented in soil or foliar test.

develop a nutrient management plan that meets their crop production and resource conservation goals.

The organic approach to nutrient management offers several advantages, including:

- Organic nutrient sources such as compost build soil health and long-term fertility.
- Best organic management builds the soil's capacity to meet crop nutrient needs.
- Legumes in the crop rotation can provide N without contributing to P excesses.
- Organic amendments provide secondary nutrients and micronutrients as well as NPK.
- Crop-livestock integration on many smaller, diversified organic operations enhances nutrient cycling and reduces fertilizer needs (see Elmwood Stock Farm story under Livestock and Grazing Management in Organic Systems).

Organic farmers face several unique nutrient management challenges, including:

- Conventional soil test recommendations and nutrient management guidelines may not work ideally for organically managed soils and organic nutrient sources.
- Timing of N release from organic materials may not match crop demand, resulting in both crop N deficiency and N losses to leaching and denitrification.
- Crop N deficiency and yield losses commonly occur during transition from conventional to organic production when the soil's capacity to mineralize N is limited.
    - Using concentrated organic fertilizers like poultry litter can compensate for the deficiency to some degree.
    - Continued reliance on concentrated organic fertilizers can delay soil improvement, increase GHG emissions, and threaten water quality through leaching and runoff.
    - Planting legume-grass sod instead of annual crops during the 3-year transition is the most effective way to build soil health and fertility,[56] though this may mean forgoing income.
- Repeated use of certain amendments can lead to other nutrient imbalances, such as the following.
    - Excess soil P and alkaline pH from raw or composted manure or poultry litter.
    - Excess soil Ca and Zn and alkaline pH from hardwood leaves or bark.
    - Excess soil K from hay or straw mulch.
- Varying nutrient content in organic inputs can complicate nutrient budgeting.

Table 6 shows the NPK removals in grain, forage, and vegetable crops at U.S. average yields for organic production, and the nutrient contents of two of the most widely used nutrient sources on organic farms (compost and commercial poultry litter fertilizer). The data illustrate the challenge organic producers face in balancing the three major nutrients. Applying either amendment at rates to replenish the N removed by harvest would add several times as much P as removed in

[56] F. Baysal-Tustas, M. Benitez, A. Camp, M.D. Kleinhenz, J. Cardina, S.A. Miller & B.B. McSpadden Gardener, *Effects of Different Organic Field Management Strategies on Soil Quality and Soilborne Diseases of Vegetable Crops,* 96 Phytopathology S11 (2006); S.S. Briar, S.A. Miller, D. Stinner, M.D. Kleinhenz & P.S. Grewal, *Effect of Organic Transition Strategies for Peri-Urban Vegetable Production on Soil Properties, Nematode Community, and Tomato Yield,* 47 Applied Soil Ecology 84 (2011); C.E. Eastman, M. Bazik, D.A Cavanaugh-Grant, L.R. Cooperband, D.M. Eastburn, J.B. Masiunas, J.T. Shaw & M.M. Wander, *Cropping Intensity and Organic Amendments in Transitional Farming Systems: Effects on Soil Fertility, Weeds, Diseases, and Insects,* U.S. Dep't. Agric. (2008), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0196786").

harvest and also overapply K for grain crops, which return much of their K to the soil in their residues.

Current Land Grant University (LGU) recommendations for N generally exceed actual harvest removals, especially for vegetable crops. N contributions from manure, compost, and legume cover crops are accounted for to determine how much additional fertilizer N is needed. N credits for organic inputs are based on the amount of N expected to be released to the current crop, typically 50 percent of total N for manure and for legume cover crops and 10–25 percent for compost. However, if these percentages are used to determine compost or manure use rates to meet the crop's entire N requirement, P surpluses accrue rapidly. Where soil test P levels are high, the criteria for CPS 590 Nutrient Management limit application rates for manure and compost amendments based on P content. Organic farmers can meet the balance of crop N need with legumes and low-P organic N sources such as feather meal or blood meal.

Table 6. Amounts (lb/ac) of N, P_2O_5, and K_2O removed in crop harvests, compared to amounts provided in a typical manure compost and poultry litter fertilizer.

Crop	**Yield**[57]	**Removed N lb/ac**[58]	**Removed P_2O_5 lb/ac**[2]	**Removed K_2O lb/ac**[2]
Cabbage	6.9 tons/ac	43	10	45
Onions	23.0 tons/ac	126	23	126
Potatoes	10.7 tons/ac	64	32	114
Spinach	4.1 tons/ac	41	10	41
Squash	6.1 tons/ac	20	7	34
Tomatoes	24.6 tons/ac	90	39	147
Corn, grain	132 bushels/ac	119	49	36
Soybean, grain	38 bushels/ac	144[59]	30	53
Wheat, grain	33 bushels/ac	40	21	12
Corn, silage	18.5 tons/ac	175	56	131
Grass hay	3.0 tons/ac	101	31	125
Amendment and analysis	**Application rate**	**Applied N lb/ac**	**Applied P_2O_5 lb/ac**	**Applied K_2O lb/ac**
Poultry fertilizer 5-4-3[60]	1.0 ton/ac	100	80	60
Compost, 1-1-1[61]	5.0 tons/ac	100	100	100

[57] National average organic yields estimated by dividing total production by total acreage in the 2021 NASS Organic Survey.
[58] Nutrient removal rates per ton for vegetable harvests based on University of Massachusetts, 2023, New England Vegetable Management Guide, Nutrient Removal from the Soil.
Nutrient removal rates per bushel for grain harvests from George Silva, 2017, Michigan State University Extension.
Nutrient removal rates for grass hay from University of California at Davis.
Nutrient removal rates for corn silage from https://www.cropnutrition.com/.
[59] Mostly fixed through Bradyrhizobium symbiosis.
[60] Rate for a popular brand of OMRI-approved poultry litter fertilizer; analyses vary somewhat among products.
[61] Typical rate for a livestock manure-bedding compost. Actual compost analyses vary widely – each batch should be tested for nutrient budgeting purposes.

The diverse rotations that many organic farmers implement can help to balance nutrient demands. Alternating vegetables (heavy K feeders, little residue) with grains (light K feeders, abundant residue) is less likely to exhaust soil reserves than intensive vegetable multicropping. Cover crops can replenish N through fixation (legumes), retrieve K from subsoil mineral reserves (grasses), and improve P availability where soil test levels are low (grasses, legumes, buckwheat).

Research findings in organic nutrient management

Healthy soils need less NPK than recommended in standard soil test reports.

Organic soil health practices build the soil's capacity to meet crop N needs through biological N mineralization from active SOM and cover crop residues. Healthy soil can greatly reduce or even eliminate N fertilizer needs. For example:

- In Clemson, SC, organic tomato and summer squash grown after a rye and crimson clover cover crop (130 lb/ac total N) on a Toccoa sandy loam (bottomland Entisol) under long-term organic management yielded well and showed no response to applied N at 50 or 100 lb/ac.[62]
- Crop need for applied N declined with increasing soil biological activity in multiple soil types across VA, NC, SC, and GA. The economic optimum nitrogen rate (EONR) for side-dressing reached zero in 21 of 57 trials with fescue forage, 6 of 11 corn silage trials, and 12 of 36 grain corn trials.[63]
- Soils on organic farms, crop-livestock integrated operations, and other farms with high level soil health practices showed higher biological N mineralization and lower N needs than conventionally managed research station soils.[64] Thus, N recommendations based on research station trials may be too high for many farms.
- In the USDA farming system trials conducted in Beltsville, MD, soil under organic rotations showed 35 percent higher N mineralization and correspondingly greater capacity to sustain yields without N fertilizer than soil under conventional rotations.[65]
- Soils under diverse organic crop rotations in upstate New York showed twice the capacity to mineralize organic N as conventionally managed soils.[66]

Best organic soil management can also reduce the need to apply P and K. In a 5-year trial in the coastal plain of South Carolina, field crops were grown organically in corn-soy-wheat rotation with winter legume-cereal cover crops on an Orangeburg loamy sand (Ultisol) that initially

[62] Robb et al., *supra* note 50.
[63] Franzluebbers, *Soil-Test Biological Activity with the Flush of CO2: III. Corn Yield Responses to Applied Nitrogen,* 82 Soil Sci. Soc. of Am. J. 708 (2018); Franzluebbers et al., *Soil-Test Biological Activity with the Flush of CO2: IV. Fall-Stockpiled Tall Fescue Yield Response to Applied Nitrogen,* 110 Agronomy J. 2033 (2018).
[64] A.J. Franzluebbers, M.R. Pershing, C. Crozier, D. Osmond & M. Schroeder-Moreno, *Soil-Test Biological Activity with the Flush of CO2: I. C and N Characteristics of Soils in Corn Production,* 82 Soil Sci. Soc. Am. J. (2018); A.J. Franzluebbers, S.C. Reberg-Horton & N.G. Creamer, *Soil Carbon and Nitrogen Fractions after 19 Years of Farming Systems Research in the Coastal Plain of North Carolina,* 84 Soil Sci. Soc. Am. J. 856 (2020).
[65] J.T. Spargo, M.A. Cavigelli, S.B. Mirsky, J.E. Maul & J.J. Meisinger, *Mineralizable Soil Nitrogen and Labile Soil Organic Matter in Diverse Long-Term Cropping Systems,* 90 Nutrient Cycling in Agroecosystems 253 (2011).
[66] S.T. Berthong, D.H. Buckley & L.E. Drinkwater, *Agricultural Management and Labile Carbon Additions Affect Soil Microbial Community Structure and Interact with Carbon and Nitrogen Cycling,* 66 Microbial Ecology 158 (2013).

tested optimum (i.e., high) in P and K. The crops required only one-half of recommended N and no additional P or K to maintain top yields.[67] The winter cover crop added 9,000 lb dry matter and contained 110 lb N, 27 lb P, and 200 lb K per acre. Over the 5-year period, soil test P and K showed no significant depletion while SOM content in the A horizon increased from 1.2 percent to 1.7 percent. Trials on multiple soil types, including on-farm trials in NC, IL, OH, and ND, have given similar results.

Over the long run, nutrients removed in harvest will need to be replenished. However, amounts needed to maintain optimal nutrient levels may be considerably less for organic than for conventional production. Organic rotations often include enough legumes to replenish half or more of N removals, and light applications of compost or manure can balance the P budget. For managing K levels, many soils contain large mineral reserves of K that deep-rooted grasses can access, grain harvests return the majority of crop K uptake to the soil in residues, and a review of multiple farming systems trials showed that standard soil test K recommendations are often several-fold higher than necessary.[68]

Timing of N mineralization must match crop N demand.

The capacity of different soils to meet crop N needs varies widely, and many organic farmers consider N management a major challenge.[69] The rate and timing of biologically mediated N release from SOM is regulated by temperature, moisture, and current soil condition. Researchers have documented the following examples of poor synchrony between nutrient release and crop demand in organic systems.

- In an organic rotation of summer broccoli followed by fall-planted strawberry, the N in broccoli residues was mineralized and lost to leaching before the strawberry crop could use it, resulting in crop N deficiency.[70]
- Fall-applied manure failed to sustain good yields in organic tomato grown the following summer, again because N was mineralized and leached before the crop was planted.[71]
- When a team of experienced organic vegetable producers sought to optimize soil health with high biomass cover crops and minimum tillage, yields decreased about 20 percent because dry soil conditions hindered N release from SOM and cover crop residues.[72]

[67] Robin Kloot, *Using Adaptive Nutrient Management to Answer "How Much Fertilizer Do You Really Need?"* The Webinar Portal (May 8, 2018), https://conservationwebinars.net/webinars/using-adaptive-nutrient-management-to-answer-how-much-fertilizer-do-you-really-need/.
[68] Kloot *supra* note 67; see also S.A. Khan, R.L. Mulvaney & T.R. Ellsworth, *The Potassium Paradox: Implications for Soil Fertility, Crop Production, and Human Health,* 29 Renewable Agric. Food Sys. 3 (2013).
[69] Snyder et al., *supra* note 10.
[70] M. Gaskell, M.P. Bolda, J. Muramoto & O. Daugovish, *Strawberry Nitrogen Fertilization from Organic Nutrient Sources,* 842 Acta Horticulturae 385 (2009); J. Muramoto, C. Shennan & M. Gaskell, *Nitrogen Management in Organic Strawberries: Challenges and Approaches,* eOrganic (Dec. 16, 2015), https://eorganic.org/node/14818.
[71] Bowles et al., *supra* note 5.
[72] Gosia Wozniacka, *Can California's Organic Vegetable Farmers Unlock the Secrets of No-Till Farming?,* Civil Eats (March 30, 2021), https://civileats.com/2021/03/30/can-californias-organic-vegetable-farmers-unlock-the-secrets-of-no-till-farming/.

- In multiple trials in northern states (IA, MI, ND, PA and WI), organic no-till field corn yields averaged 63 percent lower than the tilled treatments, partly because lower soil temperatures under roll-crimped cover crops delayed N mineralization.[73]

The first three examples occurred in central California, where the Mediterranean climatic pattern of cool, rainy winters and hot, dry summers accentuates timing challenges. Dry soil conditions during summer limit microbial activity and N mineralization, while heavy winter rains occurring when crop growth is slow (strawberry) or absent (winter fallow) leach any soluble N present in soil profile, thereby threatening water quality and increasing subsequent N fertilizer needs.

The last example illustrates the challenge of organic minimum till in colder climates with short growing seasons, where a shallow, noninversion tillage (e.g., high speed disk) to incorporate cover crops may be needed for timely N mineralization. Organic crops have performed well in roll-crimped cover crops in warmer locations.[74]

Organic fertilizers: more is not always better.

Concentrated organic fertilizers can sustain high yields but may compromise soil health, water quality, and climate. Some relevant research findings include:

- Field trials with organic broccoli in California and Oregon found EONR of 200 lb N/ac or more. When this N was provided as feather meal (13-0-0) and other high-analysis organic N sources, well over 100 lb/ac were leached and another 23 lb/ac were emitted as N_2O.[75] Providing two-thirds of the N through compost and cover crops reduced N_2O emissions by half but did not curb leaching.
- As noted earlier, organic vegetable system trials in Washington State showed that soil fertilized with poultry litter over an 11-year period showed lower microbial activity and less capacity to mineralize N from SOM than the same soil fertilized with finished compost (C:N approx. 20) at equivalent N rates.[76]
- Organic rotations that rely on poultry litter to meet crop N needs build excess soil P, which inhibits mycorrhizal fungi and can pollute nearby surface waters.[77]

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[73] K. Delate, *Developing Carbon-Positive Organic Systems through Reduced Tillage and Cover Crop-Intensive Crop Rotation Schemes,* U.S. Dep't. Agric. (2013), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0213847").

[74] G. Chen, C.R. Hooks, M. Lekveishvili, K.H. Wang, N. Pradhan, S. Tubene, R.R. Weil & R. Ogutu*, Cover Crop and Tillage Impact on Soil Quality, Greenhouse Gas Emission, Pests, and Economics of Fields Transitioning to Organic Farming,* U.S. Dep't. Agric. (2015) https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0227036"); see also Delate et al., *supra* note 6.

[75] D.P. Collins & A. Bary, *Optimizing Nitrogen Management on Organic and Biologically-Intensive Farms,* eOrganic (Oct. 25, 2017), https://eorganic.info/node/22245 (follow link to YouTube playlist and select video presentation); see also Li et al., *supra* note 46.

[76] Bhowmik et al., *Use of Biological Indicators of Soil Health to Estimate Reactive Nitrogen Dynamics in Long-Term Organic Vegetable and Pasture Systems,* 103 Soil Biology and Biochemistry 308, (2016); Bhowmik et al., *Potential Carbon Sequestration and Nitrogen Cycling in Long-Term Organic Management Systems,* 32 Renewable Agric. and Food Sys. 498, (2017).

[77] D.L. Osmond, J.M. Grossman, G. Jennings, G.D. Hoyt, M. Reyes & D. Line, *Water Quality Evaluation of Long-Term Organic and Conventional Vegetable Production under Conservation and Conventional Tillage,* U.S. Dep't. Agric. (2014), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0220146"); see also Van Geel et al., *supra* note 8, and Hu et al., *supra* note 31.

Crops often suffer yield-limiting N deficiency during the first few years after conversion from conventional to organic production and may need higher inputs of concentrated organic N to sustain production. As SOM and biological activity increase under organic management, the soil's capacity to mineralize N from SOM and crop residues can increase, allowing fertilizer inputs to be reduced. However, the farmer can face a dilemma at this point: cutting back too quickly can hurt yields, while continuing to rely on concentrated N sources can hinder or prevent the development of N mineralizing capacity. More research is needed to develop an adaptive approach to N management that can track and respond to improvements in soil health over time. Two research teams are currently working toward this goal.

- Researchers at North Carolina State University have developed a simple 3-day soil respiration lab procedure to estimate soil test biological activity. This activity correlates sufficiently well with N mineralization to provide guidance on whether and how much N to apply to the crop.[78]
- Researchers at Penn State are refining a new decision support tool for N budgeting in organic corn (grain) in Pennsylvania based on total SOM, a 24-hour respiration test, soil texture, and previous cover crop N and C:N ratio.[79]

New research-based tips for N management in organic systems.

Meta-analyses and long-term farming systems trials have begun to identify some promising solutions to organic nutrient management challenges:

- Organic N sources applied instead of conventional N at equivalent *total N* rates reduced N leaching losses 30 percent without compromising yield, while organic N at equivalent *soluble N* rates improved yields by 6 percent but also increased N leaching 21 percent.[80]
- Biochar applications can build SOC, improve yields by 12 percent, and reduce N_2O emissions by 40 percent and N leaching by 35 percent.[81]
- In the Beltsville, MD, farming system trials, poultry litter rates could be reduced by two-thirds to avoid excess P buildup without affecting corn or soybean yields.[82]
- In central California, winter cover crops planted after organic broccoli recovered over 100 lb/ac of soluble N. Organic lettuce planted after the cover crop yielded 30,000 lb/acre without additional N applications, compared to 0–15,000 lb/ac after winter fallow, in which winter rains leached the N before lettuce was planted.[83]

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[78] Franzluebbers, *Soil-Test Biological Activity with the Flush of CO2: III. Corn Yield Responses to Applied Nitrogen,* 82 Soil Sci. Soc. of Am. J. 708 (2018); Franzluebbers et al., *Soil-Test Biological Activity with the Flush of CO2: IV. Fall-Stockpiled Tall Fescue Yield Response to Applied Nitrogen,* 110 Agronomy J. 2033 (2018); see also Franzluebbers *supra* note 43, and Robb et al., *supra* note 50.

[79] White, *supra* note 1.

[80] Z. Wei, E. Hoffland, M. Zhuang, P. Hellegers & Z. Cui, *Organic Inputs to Reduce Nitrogen Export via Leaching and Runoff: A Global Meta-analysis,* 291 Agric., Ecosystems & Env't. 118176 (2021), https://doi.org/10.1016/j.envpol.2021.118176.

[81] Young et al., *supra* note 25.

[82] M. Cavigelli, *Leveraging Long-Term Agroecological Research to Improve Agronomic, Economic, and Environmental Performance of Organic Grain Production,* U.S. Dep't. Agric. (2020), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1007473").

[83] E. Brennan, *Lessons from Long-Term, Cover Crop Research in the Salad Bowl of America,* YouTube (Nov. 19, 2018), https://www.youtube.com/watch?v=JurC4pJ7Lb4.

In a study of 13 organic tomato fields in central California, Bowles et al. (2015) identified three distinct patterns:

- N-deficient: low SOC, low microbial activity, very low midseason soil nitrate-N (less than 1 ppm), low yields.
- N-saturated: moderate SOC, high microbial activity, high midseason soil nitrate-N (16 ppm), high yields.
- Tightly coupled N cycling: high SOC, high microbial activity, low midseason soil nitrate-N (3 ppm), high yields.

N-deficient fields received manure in the fall before planting and no supplemental N during the growing season. Low soil biological activity and poor timing of N mineralization resulted in crop N deficiency. N-saturated fields received 170–210 lb N/ac from one or more concentrated sources including poultry litter, seabird guano, vetch cover crop, and fish emulsion. In these soils, the abundance of soluble N promoted microbial breakdown of SOM.[84]

Tightly coupled fields received 110–160 lb N/ac, mostly from finished compost (C:N 15–18), with a supplements of soluble N (fish emulsion or Chilean nitrate) delivered in small (approx. 4 lb/ac) weekly doses through in-row drip fertigation during the time of greatest crop N demand. These soils had enhanced levels of microbial and plant root enzymes involved in N cycling, so that N was efficiently mineralized and used in the rhizosphere (root zone) while bulk-soil nitrate-N levels remained low.[85] In another study, weekly in-row drip fertigation (fish emulsion or a cyanobacteria-based liquid fertilizer) sustained lettuce yields at an EONR of just 25 lb/ac (total), which virtually eliminated N_2O emissions.[86]

These findings suggest the following "4Rs" for concentrated N in organic vegetable crops.

- *Right rate* – low rates, perhaps 20 percent of total crop N requirement.
- *Right source* – liquid fertigation (e.g., fish emulsion, cyano-fertilizer, or Chilean nitrate).
- *Right placement* – within row (drip fertigation or band application), not broadcast.
- *Right timing* – small weekly doses during peak crop N demand (drip fertigation) or at the beginning of the peak demand period (solid fertilizer).

This approach apparently gives these crops the boost they need without flooding the bulk soil with soluble N or compromising biological N cycling and SOC sequestration. More research is needed to explore whether this strategy can work for other organic crops such as broccoli, in which the use of solid organic fertilizers like feather meal (13-0-0) broadcast across the bed top yielded EONR greater than 200 lb/ac with excessive N losses.[87]

Best organic nutrient management practices

[84] T.M. Bowles, V, Acosta-Martinez, F. Calderon & L. E. Jackson, *Soil Enzyme Activities, Microbial Communities, and Carbon and Nitrogen Availability in Organic Agroecosystems across an Intensively Managed Agricultural Landscape,* 68 Soil Biology and Biochemistry 252 (2014).

[85] See *id.;* also see Bowles et al., *supra* note 5 and L. Jackson & T. Bowles, *Researcher and Farmer Innovation to Increase Nitrogen Cycling on Organic Farms,* eOrganic (Feb. 25, 2013), https://eorganic.org/node/8677.

[86] P. Toonsiri, S.J. Del Grosso, A. Sukor & J.G. Davis, *Greenhouse Gas Emissions from Solid and Liquid Organic Fertilizers Applied to Lettuce,* 45 J. Env't. Quality 1812 (2016).

[87] Collins et al., *supra* note 75; see also Li et al., *supra* note 46.

Organic and transitioning producers clearly need an adaptive approach to nutrient management, especially for N, for which conventional recommendations can result in either under- or over-fertilization depending on soil health, climate, and the crops grown. Simple on-farm trials to compare crop yields with different organic nutrient sources and rates can help farmers determine the best fertility program for their production, conservation, and economic goals.

Nutrient management criteria for CPS Organic Management include:

- Manage nutrients through crop rotations, cover crops, and application of compost, manure, and other organic nutrient sources following CPS 590 Nutrient Management:
  - Obtain nutrient analyses of compost, manure, and other organic amendments.
  - Avoid overloading soil with P or other nutrients.
- Limit the use of concentrated nutrient sources like poultry litter to no more than 50 percent of total crop N requirement.
- If high soil P limits compost and manure, increase the use of legumes for N.

The research findings discussed in the preceding section suggest the following adaptive nutrient management considerations for organic farmers implementing CPS Organic Management:

- During the early years of organic transition or restoration of a depleted soil:
  - Plant a perennial grass-legume sod for the first 3 years if practical.
  - If production is economically necessary, start with less nutrient-demanding crops.
  - For production crops, meet at least half of crop N requirement with moderate C:N inputs like finished compost and legume-cereal cover crops.
  - Provide soluble or fast-release N within crop rows (drip fertigation or band application) during times of peak crop N demand as needed.
- Plant deep-rooted cover crops promptly after harvest to retrieve and hold leftover soluble N, especially after crops with lower N use efficiency such as head brassicas.
- Consider biochar applications to enhance N cycling efficiency, especially on soil types noted as responsive to biochar in the NRCS Web Soil Survey.
- As soil health improves:
  - Base organic N input rates on total N content rather than plant-available N.
  - Gradually reduce concentrated N inputs as soil N mineralization increases.
- Use adaptive nutrient management tools to adjust and optimize N inputs over time.
  - Do side-by side rate trials for N and other nutrients to determine actual crop need.
  - Conduct foliar analyses to track crop sufficiency for N and other nutrients.
  - Obtain a soil respiration test to track soil microbial activity.
- Budget P and K inputs to maintain but not exceed optimal levels ("high" on soil test).
  - When optimum is attained, P and K inputs should roughly equal harvest removals.
  - P and K may not be needed every year. If soil test P or K rise above optimum, suspend inputs of those nutrients to draw down the excess.
  - Test soil regularly (every 1–3 years) to track trends and adjust inputs.
- If P is high or very high, use legumes instead of compost, manure, and poultry litter for N.
- Conduct complete soil and foliar nutrient analyses to track secondary and micronutrients as well as NPK.
  - Address micronutrient deficiencies to ensure efficient use of the major nutrients.

Weed, Pest, and Disease Management in Organic Farming Systems

Organic farmers take an ecological approach to weed, pest, and disease management, for which the NOP § 205.2 definition of Organic Production sets the context:

> *"A production system managed … to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity."*

The underlying philosophy of the organic method views plant-eating organisms and volunteer plants as part of the farm ecosystem and considers most weed, pest, and disease problems as symptoms of underlying ecological imbalances that must be addressed to achieve long-term solutions. Organic farmers seek to build a pest-resilient production system that:

- Enhances soil, crop, and livestock health and vigor.
- Provides habitat for beneficial insects and other organisms that help control pests.
- Minimizes opportunities for weeds, arthropod pests, parasitic nematodes, and microbial plant pathogens to grow, multiply, and threaten production.

The next step in ecological pest management is to learn the life cycles of the region's most prevalent insect and nematode pests, weeds, and plant pathogens and use that knowledge to design management strategies, as outlined in Conservation Practice Standard (CPS) Pest Management Conservation System (Code 595).

Because any substance designed to kill pest organisms can also kill nontarget organisms, upsetting ecological balance and reducing biodiversity, the organic method does not use most synthetic pesticides, herbicides, and fungicides and uses NOP-allowed pesticides only when cultural, biological, and mechanical practices prove insufficient. In addition to protecting pollinators and other aboveground beneficial organisms, this approach protects soil life and soil health. Research has shown that all classes of crop protection chemicals can harm a wide range of soil micro- and macro-organisms and that even NOP-allowed copper fungicides and vinegar-based herbicides can harm beneficial soil fungi.[88] Also, repeated use of the same pesticide often leads to pesticide resistance in target pests; some pests have become resistant to *Bacillus thuringiensis* (Bt) and Spinosad as well as NOP-prohibited synthetics.

Table 7 outlines organic pest management strategies and practices and their relationship with NRCS practices.

Table 7. Organic pest management activities and criteria in relation to existing NRCS practices.

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[88] H. Atthowe, *Outcome of Weed Management, Reduced-Tillage, and Soil Health: Weed Ecology in Biodesign Farm's Organic, Minimum-Till Vegetable Production System,* Organic Farming Research Foundation (2019), https://grants.ofrf.org/system/files/outcomes/AtthoweFinalReport_Updated2019.pdf; Puissant et al., *Quantification of the Global Impact of Agricultural Practices on Soil Nematodes: A Meta-analysis,* 161 Soil Biology and Biochemistry 108383 (2021); Vahter et al., *Landscapes, Management Practices and their Interactions Shape Soil Fungal Diversity in Arable Fields – Evidence from a Nationwide Farmers' Network,* 168 Soil Biology and Biochemistry (2022); Walder et al., *Soil Microbiome Signatures are Associated with Pesticide Residues in Arable Landscapes,* 174 Soil Biology and Biochemistry (2022); see also Gunstone et al., *supra* note 19, and Klein, *supra* note 22.

Organic Conservation Activity	Complete Coverage in Existing CPS	Partial Coverage in Existing CPS	Topics in Existing CPS	New Criteria for Organic Integrated Pest Management (IPM) Activities
Advanced IPM for insect pests	No	Pest Management Conservation System (595)	PAMS (prevention, avoidance, monitoring, and suppression)	Companion planting and farmscaping for natural enemies; trap crops
Advanced IPM for plant pathogens	No	Pest Management Conservation System (595)	Pathogen ID, considerations on weather-based disease forecasting, and preventing or managing wet soil and other conditions that favor pathogens	Disease resilient cultivars, including vegetable grafting on resistant rootstocks; anaerobic soil disinfestation and other fumigation alternatives
Comanaging weeds and soil health without herbicides	No	Cover Crop (340), Pest Management Conservation System (595)	Cover crops for weed suppression and breaking pest life cycles. Pest Management Conservation System criteria include managing erosion risks from tillage	Managing soil health, nutrients, and water to favor crops over weeds; tarping and other non-tillage weed controls
Crop rotation	No	Conservation Crop Rotation (328)	Rotation for soil, water quality, and pest management	Strategic rotations for weed management
Non-Use of Synthetics	No	Pest Management Conservation System (595)	WIN-PST pesticide risk assessment includes NOP-allowed materials	NOP-prohibited materials; NOP-allowed materials when preventive and biological controls fail

Organic IPM and NOP-allowed pest control materials and methods

CPS 595 Pest Management Conservation System provides a roadmap for integrated pest management (IPM), including prevention, avoidance, monitoring, and suppression (PAMS) activities and additional measures to protect soil, water, air, and nontarget organisms. Organic pest management without the use of synthetic agrochemicals requires a modified approach to IPM with much greater emphasis on prevention and avoidance activities, especially:

- Sanitation measures to exclude or remove pests, weed seeds, and pathogen inocula.
- Regionally adapted crop cultivars with resistance to prevalent pests and diseases.
- Soil health practices to enhance crop resilience to pests, pathogens, and weeds.

- Nutrient and water management to favor crops over weeds.
- Strategic crop rotation, cover cropping, and companion planting.
- Trap crops.
- Planting and maintaining habitat for natural enemies of insect pests.

Most organic farmers scout their fields regularly to evaluate the beneficial insect community (predators and parasitoids of pests), soil and crop health, and microclimate conditions as well as pest levels, disease signs and symptoms, and weed pressure. Monitoring tools include pheromone traps to detect pest arrival and estimate population levels and weather modeling to predict crop disease outbreaks. When prevention and avoidance prove insufficient to keep pests and pathogens below economic thresholds, organic farmers implement NOP-allowed suppression methods and materials, with preference for the least ecologically disruptive methods such as:

- Introduction and release of natural enemies of the target pest.
- Physical barriers such as row cover or tunnels.
- Biofungicides and other microbial antagonists to plant pathogens.

NOP § 205.206 states:

> *"The producer must use management practices to prevent crop pests, weeds, and diseases including but not limited to:*
>
> > *"Crop rotation and soil and crop nutrient management practices ...;*
> > *"Sanitation measures to remove disease vectors, weed seeds, and habitat for pest organisms; and*
> > *"Cultural practices that enhance crop health, including selection of plant species and varieties regarding suitability to site-specific conditions and resistance to prevalent pests, weeds, and diseases.*
>
> *"Pest problems may be controlled through ...:*
>
> > *"Augmentation or introduction of predators or parasites of the pest species.*
> > *"Development of habitat for natural enemies of pests.*
> > *"Nonsynthetic controls such as lures, traps, and repellents.*
>
> *"Weed problems may be controlled through:*
>
> > *"Mulching with fully biodegradable materials.*
> > *"Mowing.*
> > *"Livestock grazing.*
> > *"Hand weeding and mechanical cultivation.*
> > *"Flame, heat, or electrical means; or*
> > *"Plastic or other synthetic mulches ... [if] they are removed from the field at the end of the growing or harvest season.*
>
> *"Disease problems may be controlled through:*
>
> > *"Management practices which suppress the spread of disease organisms*
>
> *"When the [above] practices ... are insufficient ... a biological or botanical substance or a substance included on the National List of synthetic substances allowed for use in organic crop production may be applied to prevent, suppress, or control pests, weeds, or diseases,*

provided that the conditions for using the substance are documented in the organic system plan."

The list of NOP-allowed natural pest and pathogen control materials, especially biofungicides and bioinsecticides, continues to grow as researchers identify new beneficial microbes and develop new formulations that the Organic Materials Review Institute (OMRI) and the National Organic Standards Board determine are free from NOP-prohibited substances and are compatible with organic production. A few examples of biopesticides include:

- *Bacillus thuringiensis* (Bt), including a newer strain *Bt aizawai* for corn earworm.
- *Cydia pomonella granulovirus* against the tree fruit pest codling moth.
- *Beauvaria bassiana*, an insecticidal fungus labeled for spotted wing drosophila, thrips, aphids, whiteflies, and many other insect pests.
- Beneficial species of the fungi *Trichoderma* and *Gliocladium* and the actinobacteria *Streptomyces* that colonize plant roots and exclude soil-borne pathogens.
- A bacteriophage (virus) that attacks the fire blight pathogen *Erwinia amylovora*.
- An extract of giant knotweed and a bacterium *Bacillus mycoides* that induce systemic plant resistance to a wide range of pathogens.

Synthetic crop protection materials allowed by NOP § 205.601 include:

"As [weed controls]:

"Herbicides, soap-based – for use in farmstead maintenance … and ornamental crops.

"Mulches.

"Newspaper or other recycled paper, without glossy or colored inks.

"Plastic mulch and covers (petroleum-based other than polyvinyl chloride).

"Biodegradable biobased mulch film … produced without organisms or feedstock derived from excluded methods [genetic engineering or GMO].

"As insecticides:

"Aqueous potassium silicate [also as plant disease control]

"Boric acid – structural pest control, no direct contact with organic food or crops.

"Oils, horticultural – narrow range oils as dormant, suffocating, and summer oils [also as plant disease control]

"Soaps, insecticidal

"Sticky traps/barriers

"As insect management: pheromones

"As rodenticides – vitamin D3

"As slug or snail bait – ferric phosphate

"As plant disease control:

"…Copper oxide, copper hydroxide, copper oxychloride, copper sulfate … used in a manner that minimizes accumulation [of copper] in the soil.

"Hydrated lime

"Hydrogen peroxide

"Lime sulfur [also as insecticide]

"Peracetic acid … for fire blight

"Potassium bicarbonate

"Elemental sulfur (also as insecticide or slug/snail bait)"

As noted earlier, NOP regulations exclude the use of several naturally occurring pesticides, including arsenic, lead, nicotine sulfate, rotenone, and strychnine, because of their toxicity.

Soil-friendly weed management in organic systems

Weeds are the leading barrier to successful organic production. In the 2020 OFRF organic farmer survey, 67 percent of respondents cited weed control as a substantial challenge, compared to 31 percent citing challenges with minimizing adverse impacts of tillage on soil structure and health.[89] Understanding that repeated cultivation can degrade soil structure and harm soil life, organic farmers employ an integrated approach of multiple tactics based on an ecological understanding of the weeds on their farm.[90]

The organic weed management toolbox includes many non-soil-disturbing control tools and tactics that build on a foundation of preventive measures, including:

- Building healthy soils to support vigorous, weed-resilient production crops.
- Selecting weed-competitive crops and cultivars.
- Planting weed-suppressive cover crops (i.e., smother crops).
- Designing strategic crop rotations to disrupt weed life cycles.
- Managing nutrients and irrigation to favor crops over weeds.
- Using weed-seed-free crop seed, mulches, and soil amendments.
- Composting weedy manure or residues at high temperatures (140°F for at least 3 days).
- Preventing weed escapes from setting seed by manual rogueing, mowing, or grazing.

The best way to prevent weed problems is to keep the soil occupied by desired vegetation—production crops, cover crops, sod, and forage crops—thus closing the ecological niche for weeds. This component of organic weed management also builds and protects soil health.

Cover crops

Organic farmers use cover crops for all the purposes listed in CPS 340 Cover Crop, especially weed control and soil health and fertility.[91] Fast-growing cover crops that close canopy within a few weeks after planting and cover crop mixtures that include at least one fast-growing species suppress weeds most effectively (Figure 4). Mixing several cultivars of a single cover crop species can also enhance weed suppression.[92]

Planting cover crops promptly after harvest, using high quality seed, and increasing seeding rates by 50 percent help to ensure that the cover crop will get ahead of the weeds. Organic producers often interseed or overseed cover crops into established vegetable or field crops, a practice known as relay planting. In upstate New York, annual cover crops seeded into corn at the 5–7

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[89] Snyder et al., *supra* note 10.
[90] C.L. Mohler, J.R. Teasdale & A. DiTommaso, Manage Weeds on Your Farm: A Guide to Ecological Strategies (2021).
[91] Snyder et al., *supra* note 10.
[92] L.E. Drinkwater & M.T. Walter, *Optimizing Cover Crop Selection and Management to Enhance Agronomic and Environmental Services in Organic Cropping Systems,* U.S. Dep't Agric. (2012), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0230906").

leaf stage gave better stands than post-harvest planting.[93] Relay planting can eliminate the bare soil period between harvest and planting and thereby further reduce opportunities for weed growth (Figure 5).

Figure 4. Weed-suppressive cover crops include buckwheat (left, 14 days after planting at 100 lb/ac), southern pea (center-left, 37 days after planting at 100 lb/ac), tillage radish (center-right, about 60 days after planting at 11 lb/ac), and a mixture of mustard, Austrian winter pea, oats, and barley planted in March and photographed in June (right). All photos taken in the Appalachian region of Virginia (Floyd and Montgomery Counties).

Figure 5. Legumes interplanted with kale (left); oats interplanted into eggplant covers the ground after eggplant harvest (center-left); butternut squash overseeded with red clover (center-right) and red clover overseeded into winter rye, photographed just before grain combining (right). Photo credits: Washington State U (left); Nick Andrews Oregon State U, provided by NCAT/ATTRA (center-left and center-right); Mark Schonbeck (right).

Cover crops can be strategically selected for specific weed problems. For example, sorghum-sudangrass is especially suppressive toward the invasive creeping perennial weed Canada thistle (*Cirsium arvense*), which causes serious problems in organic grains across the North Central and Western regions and is notoriously difficult to control.[94] Researchers at Ohio State University

[93] B. Caldwell, J. Liebert & M. Ryan, *On-Farm Organic No-Till Planted Soybean in Rolled Cover Crop Mulch,* Cornell (Sept. 29, 2016), http://blogs.cornell.edu/whatscroppingup/2016/09/29/on-farm-organic-no-till-planted-soybean-in-rolled-cover-crop-mulch/; M.R. Ryan, W. Curran & S. Mirsky, *Agroecological Strategies for Balancing Tradeoffs in Organic Corn and Soybean Production,* U.S. Dep't. Agric. (2016), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1004097").

[94] Abram Bicksler & John Masiunas, *Management of Canada Thistle with Summer Annual Cover Crops and Mowing*, Midwest Organic Research Symposium (2008).

planted a sorghum-sudangrass cover crop in thistle-infested fields, then mowed when both crop and weed were several feet tall. Mowing at this stage sets the weed back while the sorghum-sudangrass regrows rapidly, expanding its root system and releasing the allelochemical sorgoleone. In the Ohio State University trials, this strategy reduced Canada thistle growth in the next year's soybean crop by 98 percent, while mowing alone or planting a buckwheat cover crop were ineffective.[95] Rotations that include alfalfa can control Canada thistle if the alfalfa forage is harvested several times per year.[96]

Strategic crop rotations

Organic farmers commonly use diverse rotations that keep the ground covered for a higher percentage of the calendar year than the standard 2-year corn-soybean rotation widely used in the North Central region. A common organic field crop rotation includes:

1. Corn
2. Winter cover
3. Soybean
4. Winter cereal grain
5. Overseed perennial forage in spring

The forage crop may consist of alfalfa, red or white clover, or a mixture of perennial legume with ryegrass, orchardgrass, timothy, or other perennial grasses. The forage is grown for 1 to 3 years and may be grazed, hayed, or mowed and left in the field. These rotations reduce annual weed populations and improve or maintain soil health, whereas a simple corn-soy rotation can build weed populations and degrade soil quality, even under organic management.[97]

When giant ragweed (*Ambrosia artemesiifolia*) became a major weed problem in the soybean phase of a 4-year organic corn-soy-wheat-alfalfa rotation, Ohio State University researchers collaborated with organic farmers to identify solutions. One of the project's farmer participants, Ed Snavely, discovered that adding a fifth year to the rotation just before soybean, beginning with an early season stale seedbed followed by buckwheat as cover crop or for grain production, sharply reduced giant ragweed pressure in soybean.[98] Replicated trials validated this strategy and the farmer further improved weed suppression by expanding to a 7-year grain and forage rotation and adding on-farm livestock production.[99]

Klaas Martens and other organic grain farmers in upstate New York are collaborating with Cornell researchers to develop strategic crop rotations that suppress weeds while reducing the

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[95] Bicksler & Masiunas, *supra* note 94; see also Midwest Organic Research Symposium (2008); J. Cardina, J. Felix, D. Doohan, D. Stinner, D & M. Batte, *Transition Strategies that Control Perennial Weeds and Build Soil,* U.S. Dep't. Agric. (2011), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0207346").
[96] Sheaffer et al., *supra* note 12.
[97] C. Reberg-Horton, *Organic Weed Management in Organic Grain Cropping Systems,* eOrganic (2012), https://eorganic.org/node/7469 (scroll to correct video); see also Hooks et al., *supra* note 6, and Sheaffer et al., *supra* note 12.
[98] D. Stinner & P.L. Phelan, *Biological Buffering and Pest Management in Organic Farming Systems: The Central Role of Organic Matter,* U.S. Dep't. Agric. (2008), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0197139").
[99] Interview with Ed Snavely (2016).

need for tillage and cultivation. They have found that roll-crimped winter rye provides selective weed control for organic no-till soybean or dry bean and protects the crop from white mold, a major disease of bean crops.[100] The rye suppresses weeds by tying up N and its roll-crimped residue blocks emergence of small-seeded annual weeds, allowing the N-fixing bean to grow with reduced weed and disease pressure. Other studies have shown similar success with organic soybean planted no-till into roll-crimped rye.[101]

Through years of careful observation of crop-weed-residue interactions, Martens (2022, personal communication) has found that:

- Adding mustard or buckwheat to grass-legume rotations reduces weedy mustard populations in winter cereals.
- Adding winter wheat to a corn-soy rotation dramatically weakens the vigor of velvetleaf, a common and problematic weed in field crops.
- Sowing rye and Austrian winter peas no-till into sorghum-sudangrass stubble (after forage harvest) improves crop establishment. The peas enhance rye vigor by contributing N, thereby providing a more effective weed-suppressive mulch when rye is roller-crimped.
- Adding winter barley to field crop rotations can reduce thistle weeds because barley is harvested when thistles are most vulnerable to mowing.

The research team is currently working to develop improved organic rotations with extended no-till sequences and enhanced soil coverage, living root, and crop diversity.[102]

Because weed species composition and the interactions of each crop with weeds, residues, and other crops in the rotation vary with seasonal temperature and moisture patterns, soil types, and production systems, strategic rotations for organic weed management are inherently region-specific. Experienced organic producers across the U.S. have developed innovative rotations for comanaging weeds and soil health at their locales.[103]

Managing nutrients and water to favor crops over weeds

Many cropland weeds respond to abundant soluble N and other nutrients in the soil with rapid emergence and aggressive growth. Pigweeds (*Amaranthus* spp.), lambsquarters (*Chenopodium album*), common chickweed (*Stellaria media*) nightshades (*Solanum* spp.), wild mustard

[100] S.J. Pethybridge & M. R. Ryan, *Breaking Down the Barriers to Organic No-Till Soybean and Dry Bean Production through Improved White Mold Management,* U.S. Dep't Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1017078"); M. Ryan, M.I. Gomez, E. Silva & S.J. Pethbridge, *Taking Tillage out of Organic Grain Crop Production with Ecology, Tools and Technology,* U.S. Dep.t' Agric. (2021), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1023545").

[101] M.E. Barbercheck, W. Curran, J. Harper, R. Hoover, D. Voight & G. Hostetter, *Improving Weed and Insect Management in Organic Reduced-Tillage Cropping Systems,* U.S. Dep't. Agric. (2014), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0218675"); K. Clark, *Organic Weed Management Systems for Missouri,* U.S. Dep't. Agric. (2019), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1004003"); see also Caldwell et al., *supra* note 93.

[102] Ryan et al., *supra* note 100.

[103] J. Bolluyt, S.E. Johnson, P. Lowy, M.T.McGrath, C.L. Mohler, A. Rangarajan, K.A. Stoner, E. Toensmeier & H. van Es, Crop Rotation on Organic Farms: A Planning Manual (C.L. Mohler & S.E. Johnson eds. 2009); U.S. Dep't Agric., Nat. Res. Conservation Serv., Organic Booklet and Factsheets, https://www.nrcs.usda.gov/getting-assistance/other-topics/organic/organic-booklet-and-factsheets.

(*Brassica kaber*), barnyardgrass (*Echinocloa crus-galli*), foxtails (*Setaria* spp), Johnsongrass (*Sorghum halapense*), and many other cropland weeds respond dramatically to soluble N and often to P and K as well.[104] Most of these weeds have small seeds and their newly emerging seedlings depend on having abundant soil nutrients to establish itself and grow rapidly. In contrast, most crops can draw on nutrient reserves from their larger seeds or transplant plugs for the first couple weeks after planting. Thus, during crop establishment, maintaining nutrients from slower release sources at moderate levels can help prevent organic crops from being overwhelmed by aggressive weed competition.[105]

Research at Cornell University has shown that growth rates of nutrient responder weeds increase with composted poultry litter application rates well above the rate for maximal crop growth (Figure 6).[106] Weed responses to individual nutrient applications of N (feather meal) or K (potassium sulfate) were less pronounced, which suggests that the weeds responded to all three major nutrients in the compost.

Optimum timing and placement of nutrients and irrigation water can also give organic crops an advantage over weeds. Nutrients delivered to crops by in-row drip fertigation, within-row sidedressing, or foliar feeding give the crop a selective boost, leaving interrow weeds unfed.[107] Delivering water within-row can favor crops over weeds, although dry interrow conditions can slow biological N mineralization and thereby limit crop growth. Some farmers lay drip tape several inches below the surface in crop rows, which can provide water to crops while leaving within-row weed seeds dry and less likely to germinate (Figure 6).

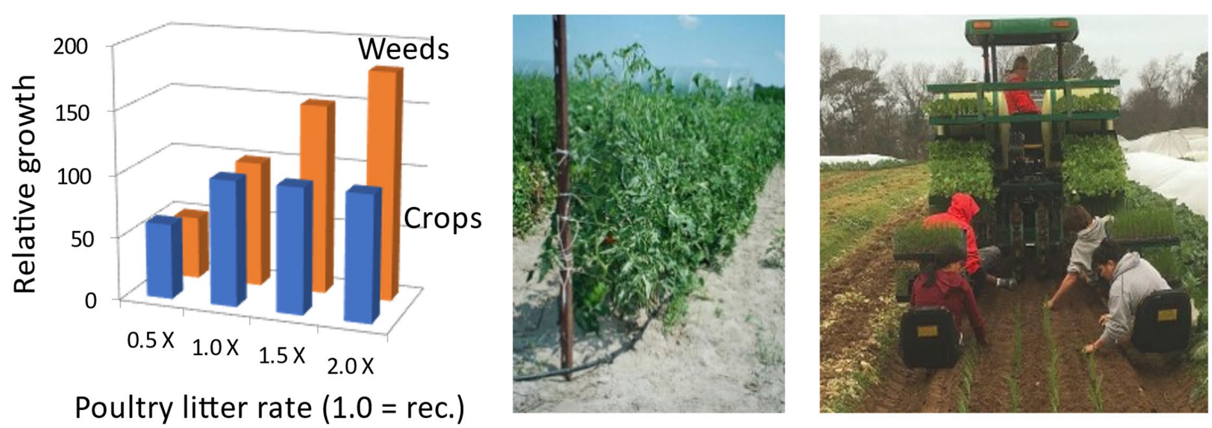

Figure 6. Cornell organic farming system studies showed that N responder weeds such as common lambsquarters, pigweed, foxtails, and common ragweed continue to respond to

[104] Mohler et al., *supra* note 90.
[105] *See id.*
[106] *Compost Experiment,* Cornell Univ. (2005), http://www.hort.cornell.edu/extension/organic/ocs/compost/index.html (click "2004, 2005" for results summary); N. Little, C. Mohler, A. DiTommaso & Q. Ketterings, *Partitioning the Effects of Nutrients from Composted Manure on Weeds and Crops: A Step Toward Integrated Crop-Weed Management,* Ne. Organic Rsch. Symp. Proc. 46 (2012); C. Mohler, T. Bjorkman & A. DiTommaso, *Control of Weed Size by Compost Application Rate in an Organic Cropping System,* Weed Sci. Soc. Am. 2008 Proc. (2008).
[107] Mohler et al., *supra* note 90.

increasing rates of composted poultry litter (N-P-K levels 4-5-2) well beyond when the growth response of crops considered heavy feeders (corn, kale) levels off (left). In-row drip irrigation selectively feeds and waters the tomato crop and reduces interrow weed pressure (center). At Mattawoman Creek Farms in Cape Charles, VA (Eastern Shore), Rick Felker and employees transplant vegetable starts over drip irrigation lines placed 4 inches below the surface to encourage deeper crop rooting while leaving near-surface weed seeds dry and dormant (right).

Organic weed control toolbox

While preventive measures reduce weed pressure in organic systems, direct weed control (suppression) activities are usually needed to sustain production, especially in annual crop rotations. Organic farmers employ several non-soil-disturbing weed control tactics that can reduce the number of tillage or cultivation operations needed. These include:

- Mulching with organic materials, black plastic film, or landscape fabric (weed mat).
- Preplant occultation (tarping) to terminate cover crops and weeds (Figure 7).
- Flame weeding.
- Mowing between established crop rows or after harvest to reduce competition and prevent seed set.
- Using NOP-allowed herbicides made of plant essential oils, vinegar, and other organic acids.
- Post-harvest grazing.

Tarping, also known as occultation, uses black landscape fabric or silage tarps to exclude light so that emerging weeds die for lack of light, providing a weed-free seedbed. Laying the tarp for several weeks immediately after flail-mowing or roll-crimping a cover crop can ensure cover crop termination and enhance weed suppression without tillage. This strategy can be practical for small-scale operations up to an acre or two, and many organic specialty crop producers are using this method to optimize soil health and weed management in high tunnels and small outdoor fields for high-value crops. Some use landscape fabric with planting holes after the initial tarping period to extend weed control through the cropping season (Figure 7).



Figure 7. Bryan Hager of Bremen, GA lays uncut landscape fabric after mowing the cover crop for a month to ensure termination and kill emerging weeds. Just before planting, he replaces it with fabric with planting holes (left). The landscape fabric is durable enough to use for many seasons and is water- and air-permeable so that it provides season-long no-till weed control in strawberries (center) and high tunnel vegetables (right) without blocking moisture or aeration.

When cultivation is needed, organic farmers have a wide range of tools from which to choose, including torsion weeders, spyders, finger weeders, knives, undercutters, and high-residue cultivators for minimum-till systems such as roll-crimped cover crop.[108] Farmers, scientists, and agricultural engineers continue to develop new tools and methods that give more weed control with less soil disturbance. Examples include new camera-guidance technology and robotics that can selectively remove weeds from within crop rows.

Practices that can improve the efficacy of cultivation include:

- Stale or false seedbed, in which the soil is tilled and the seedbed prepared, then planting is delayed, allowing weeds to germinate and emerge. The weeds are then destroyed by flame or shallow cultivation immediately before planting.
- Pre-emergence flaming or rotary hoeing, so crops emerge in a weed-free seedbed.
- Timely, shallow cultivation when weeds are just emerging, less than 1 inch tall.
- High residue cultivator for minimum-till systems such as roll-crimped cover crop.

Some new organic weed management tools and tactics in research and development include:

- Electrical weed control (weed zapper) in organic tree fruit[109] and cereal grains.[110]
- Caprylic and capric acid herbicides applied with precision spray technology to reduce spray volume 90 percent.[111]
- Stacking cultivation tools in tandem (e.g., finger weeder and whisker weeder) to enhance weed control.[112] Farmer-researcher learning network on advanced cultivation techniques at https://forum.physicalweedcontrol.org.
- Bio-based biodegradable film mulch and seeding vegetables in compost on top of the mulch.[113]
- Biodegradable hydromulch applied between vegetable rows.[114]
- Camera-guided robotic cultivation.[115]

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[108] Sustainable Agric. Rsch. Educ., Steel in the Field: A Farmer's Guide to Weed Management Tools (G. Bowman ed. 1997); see also Mohler et al., *supra* note 90.

[109] M. Moretti, B.D. Hanson, A.K. Formiga, L.M. Sosnoskie, L.J. Brewer, B. Goodrich & E. Chernoh, *Performance and Economics of Electrical Weed Control in Organic Perennial Crops: A Multiregional Approach,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1026745").

[110] Ryan et al., *supra* note 100.

[111] L. Carpenter-Boggs, *No-Till Organic Cropping System for the Dryland Pacific Northwest,* U.S. Dep't. Agric. (2021), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1023855").

[112] E. Gallandt & D. Brainard, *Integrating Advanced Cultural and Mechanical Strategies for Improved Weed Management in Organic Vegetables,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1016587").

[113] S. Wortman, *A Biobased Mulch Innovation for Organic Spinach and Carrots,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1023776").

[114] G. Gramig, S.P. Galinato, D.S. Bajwa, S.L. Weyers, L.W. DeVetter & A. Formiga, *Mulch 2.0: Biodegradable Composite Hydromulches for Sustainable Organic Horticulture,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1026762").

[115] E. Mallory, *Innovative Sowing, Cultivation, and Rotation Strategies to Address Weed, Fertility, and Disease Challenges in Organic Food and Feed Grains,* U.S. Dep't. Agric. (2020), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1007223").

- Specific biological controls including bindweed moth (*Tyta luctulosa*) and bindweed gall mite (*Aceria malerbae*) against field bindweed,[116] and thistle rust fungus (*Puccinia punctiformis*) against Canada thistle.[117]

Each of these new techniques is part of an organic weed IPM strategy undergoing testing and development through farmer-researcher collaborations supported by the USDA Organic Research and Extension Initiative or Organic Transitions research program funding. While none of these tactics alone can provide sufficient weed control, they show promise for enhancing the efficacy of crop rotation, cover cropping, and other preventive weed management practices.

Functional plant biodiversity for organic insect pest management

Crop diversity and beneficial insects play central roles in organic management of arthropod (insect and mite) pests. A diverse plant community slows the spread of pests and pathogens and provides food and habitat for natural enemies of insect pests. Organic farmers use the following plant diversity practices to support ecologically based pest management.

- Planting crops in small fields separated by hedgerows, windbreaks, or natural areas.
- Within-field crop diversification.
- Companion planting.
- Beneficial habitat plantings, farmscaping.
- Trap crops.

Pests and pathogens spread rapidly across large fields planted to a single crop (monoculture) unless the crop is treated regularly with pesticides. While crop rotation (planting different crops in successive years or cropping cycles) can slow the growth and spread of pathogenic microbes and plant-parasitic nematodes, most insect pests are sufficiently mobile to find their host crop even when crops are rotated every year. Planting two or more unrelated crops within a field can make it more difficult for pests to find and damage new areas planted to their host plant species, thus slowing their growth and reproduction. Crop diversity similarly hinders the spread of airborne or insect-vectored plant pathogens.

Practices that enhance within-field crop diversity include:

- Stripcropping (CPS 585).
- Alley cropping (CPS 311).
- Intercropping (CPS 328 Conservation Crop Rotation enhancement activity E328N).
- Dividing the field into rotation blocks, with adjacent blocks planted to different crops.

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[116] P. Carr, F.A. Menalled, P.E. Miller, J.F. Gaskin, G. Gramig, I.A. Burke, A.N. Bekkerman, B.R. Grimberg, T. Seipel, K. Fuller, E.M. Glunk, Z. Miller, A.L. Formiga, T.H. Murphy, J.O. Eberly & H.E. Estrada, *Creep Stop: Integrating Biological, Cultural, and Mechanical/Physical Tools for Long Term Suppression of Creeping Perennial Weeds in Northern Great Plains and Pacific Northwest Cropping Systems,* U.S. Dep't. Agric. (2018), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1016580"); R.E. Peachey, C.A. Mallory-Smith, Y.E. Choi & M.A. Moretti, *Harnessing the Voracity of the Biocontrol Tyta luctuosa to Improve Management of Field Bindweed during Transition to Organic and Beyond,* U.S. Dep't. Agric. (2021), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1013517").

[117] D.W. Bean, *Developing Biological Control of Canada Thistle for Colorado's Organic Producers using the Host-Specific Rust Fungus Puccinia punctiformis,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1016815").

Organic specialty crop farmers who produce a diversity of vegetables, herbs, or cut flowers often divide their fields into rotation blocks, each consisting of a single raised bed or a few beds. Adjacent blocks are planted to different phases of the crop rotation to maintain within-field diversity as each block moves through the rotation in subsequent years (Figure 8). Farmers often take an adaptive approach to the rotation that can respond to shifting market demand or growing conditions. For example, weak market demand for okra or broccoli might warrant a shift to sweet potato or cauliflower, respectively. Severe problems with late blight in tomato or cucumber beetle in cucumber might be addressed by switching to less susceptible crops such as pepper and squash.

I – Broccoli II – Tomato III – Lettuce IV – Cucumber V – Okra

	Block A	Block B	Block C	Block D	Block E
Year 1	Broccoli	Tomato	Lettuce	Cucumber	Okra
Year 2	Tomato	Lettuce	Cucumber	Okra	Broccoli
Year 3	Lettuce	Cucumber	Okra	Broccoli	Tomato
Year 4	Cucumber	Okra	Broccoli	Tomato	Lettuce
Year 5	Okra	Broccoli	Tomato	Lettuce	Cucumber

Figure 8. An example of a 5-year specialty crop rotation in which unrelated crops (e.g., broccoli, tomato, lettuce, cucumber, and okra) are rotated through five blocks within the same field on a recurring cycle. Crop categories can be expanded to enhance flexibility and responsiveness to production and market conditions (e.g., brassicas, Solanaceae, greens, cucurbits, and other crops). This scheme maintains plant diversity in space and time, so that no bed is planted to the same plant family 2 years in a row and no two adjacent blocks are planted in the same plant family.

Companion planting

Companion planting is a form of intercropping developed by early practitioners of the organic method, in which two or more dissimilar crops that have been observed to benefit each other directly are planted near one another. Often, one or more component crops in a companion planting system harbor natural enemies of pests of other crops or give off aromas that confuse or repel the pests. Many cut flowers and culinary or medicinal herbs in the umbel (Apiaceae or carrot family), composite (Asteraceae or sunflower family), sage-mint (Lamiaceae) and legume (Fabaceae) plant families provide accessible pollen and nectar, which are vital food resources for many parasitic micro-wasps and syrphid and tachinid flies that provide valuable biocontrol against many pests. For example, plantings of dill or cilantro in cucurbit crops can attract natural enemies of cucumber beetle, and sage-family herbs can enhance biocontrol of a range of pests. Some organic farmers allow a few mustard or arugula plants to bolt and flower, as their blooms attract natural enemies of cabbageworm and other brassica pests.

Other companion planting benefits that can contribute to overall crop vigor and resilience include complementary use of soil moisture (deep and shallow rooted crops), complementary nutrient dynamics (legumes and N-demanding crops), microclimate amelioration (e.g., partial shade for greens between rows of taller crops), weed suppression by a low-growing crop between rows of tall, erect crops, or mutually beneficial effects on soil and rhizosphere microbiomes. Indigenous companion planting traditions include the "Three Sisters" of corn (tall, erect, heavy feeder), beans (N fixing, can use corn as trellis), and squash (tolerates partial shade, forms long vines with heavy canopy that suppresses weeds).

Farmscaping

Farmscaping is an approach to beneficial habitat planting that aims to maintain a diversity of flowering plants throughout the growing season to provide pollen and nectar for pest predators and parasites, as well as shelter and habitat for both ground-dwelling and aerial beneficial insects. A mixture of annual and perennial flowering plants in the carrot, sunflower, legume, sage, crucifer, and other plant families with accessible nectar and pollen, including species that flower in spring, summer, and autumn, is sown adjacent to crop production areas. Because many parasitic wasps and flies are specialists that attack certain pest species, the plants selected for farmscape planting should be those that will attract natural enemies of the pests of crops to be grown. The mix may include plants such as legumes and cereal grains that host species aphids and other soft-bodied insects that will not attack the production crop. These insects provide alternative prey so that lady beetles and other predators will remain in the farm ecosystem when the target pests are temporarily absent (e.g., after crop harvest).

Many cover crops support beneficial insects. Buckwheat is one of the best nectar plants for parasitic wasps and flies and southern peas have extrafloral nectaries at the base of their petioles. Cereal grains harbor aphid species that are unlikely to infest vegetable or fruit crops and can sustain lady beetle and other key predator populations. Seed vendors that serve the organic sector offer various beneficial habitat planting mixes that combine cover crops, herbs, cut flowers, and wildflowers known to harbor beneficial insects.

Farmscape can be planted as a perimeter or border planting around a small field (beneficial habitat is one of the purposes of CPS 386 Field Border), or as habitat strips every 50 to 100 feet across a larger field to allow beneficial insects to reach all parts of the production area. Prairie strips comprised of native prairie grasses, legumes, and forbs provide beneficial habitat that can contribute to biological pest control.

One type of farmscape planting, sometimes called "beetle banks," emphasizes low-growing species like white clover, creeping red fescue and other low-growing grasses, or sweet alyssum to provide shelter for ground-dwelling generalist predators including spiders, ground beetles, and minute pirate bug. Because these organisms have relatively small ranges, beetle bank plantings may be most effective as strips maintained at intervals across the field. CPS 332 Contour Buffer Strips can provide habitat for these pest predators.

Perennial conservation buffers such as riparian forest buffers (CPS 391), hedgerows (CPS 422), and windbreak and shelterbelts (CPS 380) support beneficial organisms including birds and insects that prey on crop pests as well as pollinators and wildlife. Organic farmers often divide production areas into smaller fields surrounded by buffers or natural areas to increase the proximity of beneficial habitat to cropland that requires pest management. In a study of 52 organic farms in California, natural habitat adjacent to fields enhanced native wild bird numbers yet reduced risks of crop contamination with foodborne pathogens in bird feces. Wild birds consumed over 100 species of pest insects and contributed significantly to biological pest control.[118]

All beneficial habitat plantings must be protected from exposure to pesticides (including soaps, botanicals, and other NOP-allowed pest controls) and untimely mowing or other disturbance that could harm the beneficial organisms or disrupt their habitat.

Trap crops

A trap crop is a crop cultivar or other plant species that is more attractive to the target pest than the production crop itself. The trap crop may be sown as a perimeter around the field, an area along one side of the field, or as strips at regular intervals across the field. Examples include alfalfa to draw tarnished plant bugs away from strawberry or cotton and Blue Hubbard winter squash to draw cucumber beetles, squash bugs, and vine borers away from summer squash or cucumber.

Once the pests have moved into the trap crop, they must be prevented from reentering the production crop at economically damaging levels. This can be accomplished in several ways:

- Completing harvest of a short-season production crop such as salad greens before pests multiply and begin to disperse from the trap crop.
- Protecting the production crop with row covers after pests have moved into the trap crop.
- Destruction of pests in the trap crop by naturally occurring or introduced natural enemies.
- Vacuuming the trap crop to remove pests.
- Flaming the trap crop.
- Spraying the trap crop with an NOP-allowed pesticide.
- Destroying the trap crop by mowing or tillage.

The advantage of spraying trap crops is that it uses 80–95 percent less pesticide than if the whole field were sprayed, protects nontarget organisms outside the trap crop, and reduces both direct and environmental costs of pest control.

Crop cultivars with disease, pest, and weed resistance

Most modern crop cultivars have been bred and developed for conventional farming systems with soluble fertilizers and synthetic plant protection chemicals. Thus, these cultivars underwent

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[118] J. Owen, *Avian Biodiversity: Impacts, Risks and Descriptive Survey (A-BIRDS),* U.S. Dep't. Agric. (2020), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1007264").

little or no selection for traits such as weed competitiveness, pest resistance, or ability to thrive on slow-release organic nutrient sources. One of the leading factors in the yield gap between organic and conventional production (estimated at 20 percent for grains) is the lack of crop cultivars well suited to organic practices.[119]

Many crop cultivars with genetic resistance to one or more microbial pathogens or nematodes have been developed and released over the past 75 years. Many of the early disease-resistant cultivars had vertical resistance, that is, immunity to a specific pathogen based on a single gene. Pathogens often evolved to overcome the resistance gene and regained virulence against the resistant cultivar. More recent efforts have sought to develop cultivars with horizontal disease resistance, which gives a less complete yet more stable protection from one or more pathogens based on multiple genes with different modes of action.

Plant breeding for organic farming systems

Over the past 20 years, the USDA Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) have supported several robust farmer-participatory plant breeding networks to develop crop cultivars for organic systems. University researchers working in collaboration with organic farmers, nongovernmental organizations such as the Organic Seed Alliance (OSA), and small seed companies such as Commonwealth Seed Growers in Virginia and High Mowing Organic Seeds in Vermont have begun to develop crop cultivars with priority traits for organic producers, including:

- Disease resistance.
- Capacity to outcompete or tolerate weeds.
- Enhanced nutrient and water use efficiency.
- Rapid emergence, seedling vigor
- Resilience to abiotic stresses such as drought, flood, and temperature extremes.
- Flavor, nutritional value, and other market traits.

Examples of disease-resilient cultivars developed through these breeding endeavors include:

- South Anna butternut squash with downy mildew resistance, superb flavor, and long shelf life. (Commonwealth Seed Growers).
- Commonwealth Pickler cucumber with downy mildew and bacterial wilt resistance and excellent flavor (Commonwealth Seed Growers).
- Iron Lady tomato with resistance to early and late blights and Septoria (High Mowing Organic Seeds).
- Six dry bean releases that combine heirloom flavors and colors with resistance to bean common mosaic virus and higher yields (University of California at Davis).
- USDA-Maia yellow onion with resistance to onion thrips, Fusarium basal rot, and pink root (USDA).

Several OREI-funded farmer-researcher plant breeding networks are stacking multiple traits, including resilience to weed, disease, and pest pressures. For example, Carrot Improvement for

[119] R. Hultengren, M. Glos & M. Mazourek, *Breeding Research and Education Needs Assessment for Organic Vegetable Growers in the Northeast,* Cornell Univ. (2016) http://hdl.handle.net/1813/44636; L.C. Ponisio, L.K. M'Gonigle, K.C. Mace, J. Palomino, P. de Valpine & C. Kremen, Diversification Practices Reduce Organic to Conventional Yield Gap, 282 Proc. R. Soc. B 20141396 (2014).

Organic Agriculture (CIOA) has developed breeding lines that combine weed competitiveness (rapid emergence and large canopy) and resistance to *Alternaria* leaf blight and root-feeding nematodes with improved flavor and other market traits.[120] Several red and yellow carrot cultivars with moderate resistance to Alternaria were recently released, though are not yet in seed catalogues.

Carrots host rhizosphere and endophytic bacteria within the root tissue that aid in nutrient uptake and induce systemic resistance (ISR) to leaf blight, and crops growing in healthy, organically managed soils show increased capacity to associate with these beneficial microbes.[121] Researchers have documented genotypic variation among cultivars in responsiveness to beneficial soil biota, and the CIOA team has received additional funding to research and develop new cultivars with enhanced root-soil microbiome interactions for disease resistance and nutrient use efficiency.[122]

The Tomato Organic Management and Improvement (TOMI) project has documented tomato root-soil microbiome interactions that can induced systemic resistance (ISR) to two serious foliar diseases, late blight and gray mold. Researchers have identified varietal differences in the level of ISR response to the beneficial fungus *Trichoderma harzianum*, with land races showing greater ISR response than modern cultivars.[123] In its farmer-participatory breeding program, the TOMI team has selected for beneficial plant-microbe relationships that suppress disease through direct antibiosis as well as ISR. In addition, TOMI is currently refining several breeding lines that combine high yield, good flavor, and resistance to multiple pathogens.[124]

A nationwide network of farmers is selecting and developing new cover crop cultivars of hairy vetch, crimson clover, winter pea, and cereal rye for weed suppression and soil fertility in organic production systems. Selection traits include emergence and early vigor, high biomass,

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[120] P.W. Simon, *CIOA 2- Carrot Improvement for Organic Agriculture with Added Grower and Consumer Value,* U.S. Dep't. Agric. (2021), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1010332"); P.W. Simon, J. Navazio, M. Colley, L. Hoagland & P. Roberts, *Carrot Improvement for Organic Agriculture With Added Grower and Consumer Value,* U.S. Dep't. Agric. (2016), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0226276").

[121] Abdelrazek, *supra* note 23.

[122] S. Abdelrazek & L.A. Hoagland, *Potential Functional Role of Carrot Endophyte Communities,* ASA, CSAA and SSSA Int'l. Ann. Meeting (Oct. 2017); P.W. Simon, P.A. Roberts, E. Silva, T. Waters, L. Hoagland, M. Colley, J. Zystro, L. McKenzie, J. Sidhu, J.C. Dawson & Z. Freedman, *Carrot Improvement for Organic Agriculture: Leveraging On-Farm and Below Ground Networks,* U.S. Dep't. Agric. (2021), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1026624").

[123] L.A. Hoagland, *Practical Approach to Controlling Foliar Pathogens in Organic Tomato Production through Participatory Breeding and Integrated Pest Management,* U.S. Dep't. Agric. (2018), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1026624"); L. Zubieta & L.A. Hoagland, *Effect of Domestication on Plant Biomass and Induced Systemic Resistance in Tomato (Solanum lycopersicum L.),* ASA, CSSA, & SSSA Int'l. Ann. Meeting (Oct. 24, 2017).

[124] L. Hoagland, D.S. Egel, J.M. Davis, J.R. Myers, T. Mengiste, M. Colley, S. Gu, J. Dawson, R. Fulk & A. Jaiswal, *Tomato Organic Management and Improvement Project (TOMI): Part II,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1020524").

winter survival, spring vigor, and disease resistance, all important for a cover crop's capacity to suppress weeds.[125]

Efforts to develop improved wheat cultivars for organic systems have focused on weed tolerance, N use efficiency, and yield. Researchers have identified considerable variability among wheat cultivars in weed-competitive traits including height, vigor, tillering, dense canopy, and earlier maturity.[126]

Grafting

Horticulturist have grafted scions of desired cultivars onto rootstocks to enhance vigor, longevity, or disease resistance in woody horticultural crops for more than 2,000 years. During the 20th century, grafting became a major disease management practice for fruit crops, and producers in China and Japan adapted the practice for tomato, eggplant, cucumber, and other high value, disease-prone vegetable crops. Vegetable grafting has become increasingly popular in the U.S. since the turn of the 21st century and it shows promise for organic disease IPM.

Louws and Rivard (2011) have used tomato rootstock genetics to optimize plant-soil-microbe interactions to suppress soilborne pathogens and root-feeding nematodes. Several of the rootstocks they have studied, including Beaufort, Maxifort, and Big Power, give resistance to southern root knot nematode (*Meloidogyne incognita*), southern stem blight (*Sclerotium rolfsii*), and fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*), all of which cause severe damage to non-grafted heirloom tomato cultivars. In an on-farm trial in North Carolina, grafting Celebrity scions onto a disease-resistant rootstock (RST-04-105-T) protected the field-grown crop from a severe outbreak of southern stem blight and had triple the yields of ungrafted Celebrity.[127] On-farm grafting entails learning a new skill and some added production costs for rootstock seed, grafting supplies, and labor, estimated at about $2,300 per acre in this trial. However, net returns in the field trial increased by $50,000 per acre, showing the potentially high return on investment for this organic disease management strategy.

Varietal resistance as a component of organic IPM

Several research teams are combining crop genetic resilience to disease, pest, and weed pressures with biological, cultural, and physical control tactics to develop new cutting-edge IPM strategies for organic crops. For example, researchers at Texas A&M University identified rice cultivars with enhanced weed-competitive traits (tall stature, aggressive growth, strong tillering) and

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[125] V. Moore, R.J. Hayes, S. Zwinger, R. Stupar, M.R. Ryan, S.B. Mirsky, N.J. Ehlke, R.J. McGee, C. Reberg-Horton, H. Riday & R.G. Leon-Gonzalez, *Expanding the Cover Crop Breeding Network: New Species and Traits for Organic Growers,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1026683").

[126] S.S. Jones, B.K. Baik, L. Carpenter-Boggs & B.J. Goates, *Developing Wheat Varieties for Organic Agricultural Systems,* U.S. Dep't. Agric. (2011), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "0207321"); K.M. Murphy, J.C. Dawson & S.S. Jones, *Relationship among Phenotypic Growth Traits, Yield and Weed Suppression in Spring Wheat Landraces and Modern Cultivars,* 105 Field Crops Rsch. 107 (2008); M. Worthington, S.C. Reberg-Horton, G. Brown-Guedira, D. Jordan, R. Weisz & J.P. Murphy, Morphological Traits Associated with Weed-Suppressive Ability of Winter Wheat against Italian Ryegrass, 55 Crop Sci. 50 (2015).

[127] S. O'Connell, *Outcome of Grafting Tomatoes on Disease Resistant Rootstocks for Small-Scale Organic Production,* Organic Farming Rsch. Found. (2009), https://grants.ofrf.org/node/1186.

resistance to narrow brown leaf spot disease and rice water weevil. When preceded by ryegrass or clover cover crops for N and weed control and combined with 50 percent higher seeding rates, seed treatment with disease suppressive microbes (*Bacillus subtilis, B. pumilus*, fungal endophytes), and gibberellic acid (to speed seedling growth), these resilient cultivars gave economically profitable production of organic rice.[128]

Researchers and farmers in upstate New York collaborated to develop IPM strategies against onion thrips and prevalent onion diseases. They completed development and release of the storage onion cultivar USDA Maia with resistance to thrips and some diseases and used it in conjunction with OMRI-listed biopesticides and silver reflective film mulch for thrips IPM.

Varietal resistance plays a central role in disease IPM for organic tomato. For example, the TOMI project is evaluating combinations of NOP-allowed biofungicides, different kinds of compost, and soil health practices with plant genetics to build disease-suppressive soils and disease-resilient crops with strong ISR response.[129] Researchers in North Carolina are using a combination of plant breeding and grafting to tackle the three leading foliar diseases in the region (early blight, late blight, and Septoria) and soil-borne diseases, particularly southern stem blight.[130] An integrated strategy of grafting, virus-resistant cultivars, crop rotation, and biological disease controls proved effective for high tunnel organic tomato in Florida.[131]

Organic alternatives to soil fumigation

Conventional production of disease-prone specialty crops like strawberry and some vegetables often entails soil fumigation with powerful volatile chemicals to destroy crop pathogens. Fumigation also kills off much of the soil microbiome and poses significant environmental and farmworker health hazards. Organic farmers and researchers have developed several alternatives to conventional fumigants, including:

- Soil solarization – covering the soil with clear plastic for several weeks, which creates sufficient heating to kill plant pathogens and near-surface weed seeds.
- Biofumigation – tilling in a crucifer cover crop or mustard seed meals, which release isothiocyanates (toxic to pathogens and weed seeds) as they decompose.
- Biosolarization – tilling a cover crop and covering the soil with clear plastic.
- Anaerobic soil disinfestation – using organic amendments and soil saturation to create a burst of anaerobic microbial activity that kills the target pathogen.

Although each of these treatments delivers a shock to the entire soil microbiome, beneficial microbes appear to recover more rapidly after these treatments than after conventional fumigation. After solarizing the soil for disease control, organic farmers often apply finished

[128] X. Zhou, *Sustainable and Profitable Strategies for Integrated Pest Management in Southern Organic Rice,* U.S. Dep't. Agric. (2018), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1007759").
[129] D.L. Egel, L. Hoagland & A.K. Jaiswal, *Organic Tomato Foliar Pathogen IPM Webinar,* eOrganics (2018), https://eorganic.org/node/24154; see also Hoagland et al., *supra* note 124.
[130] D. Panthee, F. Louws, R.A. Dean, T. Adhikari, Y.Y. Oh, R. Shekastband & J. Zhang, *Integrated Disease Management Strategies for Key Diseases in Organic Tomato Production System,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1027175").
[131] X. Zhao, M.E. Swisher, A. Bolques, C. Hodges, T. Coolong, Z. Gao, J.C. Diaz-Perez, N.S. Dufault, J.C. Legaspi & S. O'Connell, *Adapting and Expanding High Tunnel Organic Vegetable Production for the Southeast,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1013077").

compost, worm castings, mycorrhizal fungi, or other microbial inoculants to ensure that soil biological functions are restored.

Mustard seed meal against orchard replant disease

The orchard replant disease complex, caused by pathogenic fungi (*Rhizoctonia, Cylindrocarpon*), oomycetes (*Pythium, Phytophthora*), and the lesion nematode (P*ratylenchus penetrans*), imposes severe constraints on organic fruit production and orchard renovation. Soil incorporation of mustard seed meals at 3 tons/ac the autumn before tree planting suppressed the pathogen complex and improved tree survival and growth more effectively than the conventional fumigant Telone C17 (1,3 dichloropropene and chloropicrin).[132] The isothiocyanates released from the seed meal dissipated within 2 days, yet suppression of *Pythium* and *Pratylenchus* continued for several years after a single application.[133] Protection from Telone C17 lasted only one year, and replanted orchard trees showed the best survival and growth after the seed meal treatment.[134]

The mustard seed meal treatments induced marked changes in the soil microbial community, with increased populations of known pathogen antagonists such as *Trichoderma* spp. and nematode-trapping fungi. In contrast, the soil microbial community showed little change in composition upon recovery from conventional fumigation.[135] In addition, growing the Lewjain cultivar of wheat in orchard soil before planting apple trees greatly reduced *Rhizoctonia* damage to apple roots by enhancing the growth of disease-suppressive *Pseudomonas* bacteria. In greenhouse trials, sterilizing the soil after growing Lewjain wheat or adding mustard seed meal eliminated the disease-suppressive effects, thus confirming that these treatments provide biological rather than chemical disease control.[136]

Apple rootstock genotype modulated treatment efficacy. For tolerant rootstocks (Geneva type), mustard seed meal successfully prevented replant disease at lower rates (1–2 ton/ac), which are more economically feasible for producers.[137]

Anaerobic soil disinfestation

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[132] M. Mazzola, S.S. Hewavitharana & S.L. Strauss, *Brassica Seed Meal Soil Amendments Transform the Rhizosphere Microbiome and Improve Apple Production through Resistance to Pathogen Reinfestation*, 105 Phytopathology 460 (2015).
[133] M. Mazzola, *Managing Resident Soil Biology for Tree Health,* Wash. State Univ. (2016), https://wpcdn.web.wsu.edu/cahnrs/uploads/sites/32/Organic-Soil-P1779.pdf; M. Mazzola*, Manipulation of the Soil Microbiome to Advance Orchard System Resilience,* U.S. Dep't. Agric. (2017), https://www.ars.usda.gov/ARSUserFiles/np305/GrapeandWine/2017%20Grape%20Research%20Workshop/15%20-%20Mazzola.pdf; D. Muditha N. Weerakoon, Catherine L. Reardon, Timothy C. Paulitz, Antonio D. Izzo & Mark Mazzola, *Long-Term Suppression of* Pythium abappressorium *induced by* Brassica juncea *Seed Meal Amendment is Biologically Mediated,* 51 Soil Biology and Biochemistry 44 (2012).
[134] Mazzola*, Manipulation of the Soil Microbiome to Advance Orchard System Resilience,* U.S. Dep't. Agric. (2017).
[135] Mazzola et al., *supra* note 132.
[136] M. Mazzola, *Managing Resident Soil Biology for Tree Health,* Wash. State Univ. (2016).
[137] L. Wang & M. Mazzola, *Interaction of Brassicaceae Seed Meal Soil Amendment and Apple Rootstock Genotype on Microbiome Structure and Plant Disease Suppression,* 109 Phytopathology 607 (2019).

Anaerobic soil disinfestation (ASD) was first developed by greenhouse growers in the Netherlands and Japan and more recently adapted for field production of organic specialty crops in the U.S. In ASD, a carbon source (e.g., rice hulls) is tilled in at 5–9 tons/ac, after which the soil is watered to saturation and covered with plastic film or nonporous tarp for 3–6 weeks. The resulting burst of anaerobic microbial activity kills some pathogens and modifies the soil microbiome to favor long-term disease suppression.[138] ASD requires a readily available organic carbon source, such as orchard grass, rice bran, or mustard seed meal to suppress disease. ASD treatment had little impact on the target pathogens (*Rhizoctonia* and lesion nematodes) and the soil microbiome when finished compost was incorporated before irrigation and tarping.[139]

When implemented just before strawberry planting in a 4-year organic vegetable-strawberry rotation in California, ASD reduced populations of the virulent strawberry pathogen *Verticillium dahliae* by 80 percent and improved yields and net returns. Because it is at least as effective as methyl bromide in controlling strawberry diseases and is much safer for workers, soil health, and the environment, ASD has been widely adopted by organic and nonorganic strawberry farmers in California.[140]

ASD trials with organic strawberry in Tennessee have given excellent initial results with a 98 percent reduction in *Fusarium oxysporum* populations with no adverse impacts on the indigenous fungi *Trichoderma* or *Aspergillis*.[141] A wheat crop in the vegetative or early reproductive phase served as the carbon source; mature wheat was not effective. Additional trials on field and high tunnel organic vegetables and strawberry in Pennsylvania and Florida will evaluate the impacts of ASD with different cover crops and carbon amendments on soilborne pests, weeds, diseases, and the soil microbiome.[142]

Livestock and Grazing Management in Organic Systems

Early practitioners of the organic method viewed livestock as an integral part of the farm ecosystem, and organic practices were developed in small to midscale operations that included farm animals, feed grain and forage crops, and crops for human nutrition.[143] Instead of soluble fertilizers that feed the crop but not the soil, organic farmers returned their animals' manure to the fields to sustain fertility. Farms that produced only crops and relied on off-farm inputs to restore fertility or produced only livestock and relied on purchased feed were considered

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[138] C. Shennan & J. Muramoto, *Anaerobic Soil Disinfestation to Control Soil Borne Pathogens: Current Research Findings and On-Farm Implementation,* eOrganics (2014), https://eorganic.org/node/10408; see also Mazzola, *supra* note 134.
[139] Mazzola, *supra* note 134.
[140] C. Shennan, J. Muramoto & S.T. Koike, *Integrated Soil-Borne Disease and Weed Management for Organic Strawberries using Anaerobic Soil Disinfestation, Broccoli Residue Incorporation, and Mustard Cake Application,* Organic Farming Rsch. Found. (2014), https://grants.ofrf.org/node/797.
[141] D.M. Butler, *Enhancing Indigenous Soil Microflora to Facilitate Organic Transition in the Southeastern US,* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1020752").
[142] F. Di Gioia, X. Zhao, J. Hong & F. Dini Andreote, *Anaerobic Soil Disinfestation for Enhancing and Advancing the SustainabilitY of Organic Specialty Crop Production Systems (ASD-EASY Organic),* U.S. Dep't. Agric. (2022), https://portal.nifa.usda.gov/enterprise-search/project_details (search for "1026721").
[143] Howard, *supra* note 1; see also Pfeiffer, *supra* note 1.

incomplete systems and inherently more subject to imbalances leading to poor soil, plant, animal, and human health.

Modern agriculture has separated crop production from livestock to a great degree. Large-scale conventional operations rarely produce both plant- and animal-based foods for human consumption, and many confined animal feeding operations rely entirely on off-farm sources of feed. This separation has made conventional crop production more dependent on soluble fertilizers and resulted in tremendous accumulations of excess nutrients at these operations, creating major conservation challenges related to water quality and soil health. While some large-scale organic poultry and livestock operations also specialize in one or two animal products, most organic livestock operations grow at least some of their own hay, pasture, or feed grain. Many small, diversified operations produce and market meat, dairy, or eggs as well as vegetables, fruit, specialty grains, or other plant-based foods. Integrating crop and livestock production enhances within-farm nutrient cycling, reduces reliance on off-farm sources of nutrients, and reduces potential nutrient loads on surface water and groundwater resources.

Most organic livestock farmers provide their animals and birds with as much access to the outdoors and pasture as practical within the constraints of their land resources and climate. Organic animal husbandry without the routine use of antibiotics, hormones, dewormers, and other synthetic medications requires diligent preventive care and healthy living conditions, including fresh air, clean water, good pasture, and exercise as well as shelter from inclement weather. Organic farmers attend to the welfare and comfort of their livestock to minimize animal stress and suffering, sustain productivity and health, and meet their customers' expectations that their organic meat, dairy, and eggs come from humanely raised livestock with access to pasture.

Table 8 outlines organic livestock management activities and their relationship with NRCS practices.

Table 8. Organic livestock management activities and NRCS practices.

Organic Conservation Activity	Complete Coverage in Existing CPS	Partial Coverage in Existing CPS	Topics in Existing CPS	New Criteria for Organic Livestock Management
Preventive animal health care	No	Prescribed Grazing (528), Feed Management (592)	Forage quality, nutritional balance in feed & supplements.	Organic feed and forage; healthful living conditions, outdoor access.
Pasture-based livestock production system that protects water and soil	No	Prescribed Grazing (528), Pasture and Hay Planting (512), Silvopasture (381), Fence (382), Livestock Pipeline (516), Watering Facility (614), Livestock Shelter (576)		Minimum 30 percent dry matter intake from pasture during grazing season for ruminants. Protect water resources from nutrients and pathogens.

Organic Conservation Activity	Complete Coverage in Existing CPS	Partial Coverage in Existing CPS	Topics in Existing CPS	New Criteria for Organic Livestock Management
Crop-livestock integration	No	Prescribed Grazing (528), Silvopasture (381)	Forage quality, water and soil resource concerns	Manure to harvest intervals for food safety. Crop-livestock rotation, nutrient cycling.
Composting on-farm generated manure	No	Composting Facility (317),	Facility for making and storing compost	Making and using compost. Composting manure to stabilize nutrients.
No routine use of synthetic hormones or antibiotics when animals are not sick.	No			NOP-allowed and -prohibited substances for livestock; must treat sick animals and not sell as organic.

Meeting NOP Regulations for Organic Livestock Production

NOP §§ 205.236, 205.237, 205.238, 205.239, and 205.240 regulations for organic livestock include:

> *“Livestock products that are to be sold, labeled, or represented as organic must be from livestock under continuous organic management from the last third of gestation … except that … edible poultry products must be from poultry that has been under continuous organic management beginning no later than the second day of life.*
>
> *“The producer … must provide livestock with a total feed ration composed of agricultural products, including pasture and forage, that are organically produced and handled.*
>
> *“During the grazing season, producers shall … provide pasture of a sufficient quality and quantity to graze throughout the grazing season and to provide all ruminants … with an average of not less than 30 percent of their dry matter intake from grazing.*
>
> *“Ruminant animals must be grazed throughout the entire grazing season for the geographical region, which shall be not less than 120 days per calendar year.*
>
> *“The producer must establish and maintain preventive [livestock] health care practices, including:*
>
> > *“Selection of species and types of livestock with regard to suitability for site-specific conditions and resistance to prevalent diseases and parasites.*
> > *“Provision of a feed ration sufficient to meet nutritional requirements.*

"Establishment of appropriate housing, pasture conditions, and sanitation practices to minimize the occurrence and spread of diseases and parasites.
"Provision of conditions which allow for exercise, freedom of movement, and reduction of stress appropriate to the species.
"[Performance of physical alterations as needed to promote the animal's welfare and] in a manner that minimizes pain and stress.
"Administration of vaccines and other veterinary biologics.

"When preventive practices and veterinary biologics are inadequate to prevent sickness, [a producer may administer synthetic medications. If the medication is not on the National List of allowed synthetics, the animal or its products cannot be sold as organic.]
"The producer of an organic livestock operation must not:
"Administer synthetic parasiticides on a routine basis… or to slaughter stock.
"Administer animal drugs in violation of the Federal Food, Drug, and Cosmetic Act.
"Withhold medical treatment from a sick animal … to preserve its organic status.

"The producer … must establish and maintain year-round livestock living conditions which accommodate the wellbeing and natural behavior of animals, including:
"Year-round access for all animals to the outdoors, shade, shelter, exercise areas, fresh air, clean water for drinking, and direct sunlight, suitable to the species, its stage of life, the climate, and the environment.
"Animals may be temporarily denied access to the outdoors [due to inclement weather, animal health care needs, risks to soil and water quality, and other circumstances warranting temporary shelter and confinement].
"Yards, feeding pads, and feedlots may be used to provide ruminants with access to the outdoors during the non-grazing season and supplemental feeding during the grazing season … shall be large enough to [accommodate animals] without [crowding or] competition for food … shall be well-drained, kept in good condition (including frequent removal of wastes), and managed to prevent runoff of wastes and contaminated waters to adjoining or nearby surface water and across property boundaries.
"Continuous total confinement of any animal indoors [or] of ruminants in yards, feeding pads, and feedlots is prohibited.
"For all ruminants, … daily grazing throughout the grazing season
"Shelter designed to allow for:
"Sufficient space and freedom to…express normal patterns of behavior.
"Temperature level, ventilation, and air circulation suitable to the species.
"Reduction of potential for livestock injury.

"The producer of an organic livestock operation must manage manure in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, heavy metals, or pathogenic organisms and optimizes recycling of nutrients and must manage pastures and other outdoor access areas in a manner that does not put soil or water quality at risk.

"The producer of an organic livestock operation must, for all ruminant livestock on the operation, [include] in the organic system plan, a functioning management plan for pasture.
"Pasture must be managed as a crop in full compliance with [NOP land requirements, soil fertility, and crop production standards.]

"Producers must provide pasture … to provide a minimum of 30 percent of a ruminant's dry matter intake [during] the grazing season … to minimize the occurrence and spread of diseases and parasites; and … to refrain from putting soil or water quality at risk.
"The pasture plan may consist of a pasture/rangeland plan developed in cooperation with a Federal, State, or local conservation office … The pasture plan shall include a description of:

> *"Types of pasture provided to ensure that the feed requirements … are being met.*
> *"Cultural and management practices to be used to ensure pasture of a sufficient quality and quantity … throughout the grazing season ...*
> *"Grazing season for the livestock operation's regional location.*
> *"Location and size of pastures, including maps giving each pasture its own identification.*
> *"The types of grazing methods to be used in the pasture system.*
> *"Location and types of fences, except for temporary fences, and the location and source of shade and the location and source of water.*
> *"Soil fertility and seeding systems.*
> *"Erosion control and protection of natural wetlands and riparian areas practices."*

All livestock producers are challenged to maintain animal nutrition and health and to protect water resources and air quality from nutrients, pathogens, and other contaminants from pasture runoff, feedlots, and manure storage facilities. Challenges specific to organic livestock farmers include:

- Obtaining sufficient, affordable certified organic feed grains and supplements.
- Ensuring sufficient quantity and quality of pasture or range for providing at least 30 percent of ruminant dry matter intake throughout the grazing season.
- Managing livestock parasites without the use of NOP-prohibited medications, especially for small ruminants.
- Preventing and managing other livestock diseases, segregating sick animals treated with NOP-prohibited medications from animals to be sold as organic, and managing associated financial impacts.
- Meeting NOP and food safety requirements related to manure in operations that market both animal products and vegetables, fruit, or other plant-based food products.

NRCS Conservation Practice Standards (CPS) Pasture and Hay Planting (Code 512), Prescribed Grazing (Code 528), Silvopasture (CPS 381), and supporting practices such as Fence (CPS 382), Livestock Pipeline (CPS 516), Watering Facility (CPS 614), Livestock Shelter (CPS 576), and Stream Crossing (CPS 578) can help organic producers achieve their resource stewardship goals and meet NOP requirements for a pasture plan that protects water and soil quality. Organic livestock producers who compost manure and other organic wastes of their operations to facilitate land application and enhance soil health can benefit from CPS 317 Composting Facility and CPS 316 Animal Mortality Facility. Producers can also implement CPS 592 Feed Management using certified organic grains and forages and NOP-allowed supplements.

Crop-livestock integration and cycling of resources in an organic operation: Elmwood Stock Farm

Elmwood Stock Farm, managed by John Bell, Ann Bell, and Mac Stone, produces organic beef, pork, lamb, chicken, turkey, eggs, and a wide range of vegetables for an 800-family Community

Supported Agriculture (CSA) and other markets. Of their 550 acres, they grow crops on about 200 acres of the most level land and keep the rest in permanent pasture, silvopasture, and woodland. Their highly integrated crop-livestock system maximizes within-farm nutrient cycling and maintains soil health through an 8-year crop and pasture rotation on the 200 arable acres.

- Years 1–3: Vegetable crops for the CSA with winter cover crops *or* a feed grain rotation for on-farm use.
- In the fall of year 3, a mixture of perennial grasses (festulolium, fescue, orchardgrass, bluegrass), perennial legumes (alfalfa or clovers), and forbs (plantain) are sown with a cereal grain nurse crop. If fall planting conditions are unfavorable, the pasture mix is sown in April of year 4 with an oats nurse crop.
- Years 4–8: Pasture with multispecies mob grazing. Pasture is grazed intensively for 1 to 4 days, 3 to 5 times a year. Wintertime outdoor hay feeding recycles additional nutrients for future crop production.
- Sod is broken by intensive grazing in fall of year 8 followed by tillage the next spring.

Scientists at the University of Kentucky have conducted studies on this rotation and found that, while 3 years of annual crop production with some tillage draws down soil organic matter (SOM) and organic N reserves, the 5 years in sod and management intensive rotational grazing restore total and active SOM, soil organic N, and microbial community structure to levels like permanent pasture.[144]

Elmwood Stock Farm produces essentially all the feed grain needed for their hogs, poultry, and turkeys with the following rotation.

- Year 1: Plow sod and plant field corn, followed by a winter cover crop.
- Year 2: Soybean followed by winter wheat or barley.
- Year 3: Harvest cereal grain and plant perennial grass-legume-forbs mix.
- Years 4 – 8: Pasture with mob grazing as described above.

In addition to returning nutrients to cropland through grazing (including about 80 percent of nutrients the animals and birds consume in farm-grown grain), the farm limits nutrient exports to ready-to-prepare foods that go to their CSA customers and other markets. They sell products and return the residues and trimmings of the vegetables to the land. Occasionally, the farmers sell surplus grain or buy organic grain when drought lowers yields and leaves the farm short of feed.

As a result of this high level of nutrient cycling, coupled with N-fixing legumes in the rotation, annual off-farm nutrient inputs are limited to:

- Two tons of potassium sulfate.
- Two tons of high-calcium limestone.
- Two tons of Redmond salt for livestock.
- Two tons of a mineral-oyster shell-fishmeal livestock feed supplement.
- Three hundred to four hundred pounds of solid N-P-K levels 10-2-8 or 5-6-6.
- Ten gallons of liquid N-P-K levels 3-1-1 for growing vegetable starts and high tunnel crops.

[144] Lin et al., *supra* note 13.

Together, these inputs add about 4 lb K and less than 1 lb each N and P per acre annually over the farm's 550 acres.

These strategies enable Elmwood Stock Farm to avoid the nutrient excesses or depletion that can occur when intensive crop and livestock production are separated from one another or when organic cropping operations rely on manure and compost from off-farm sources to maintain SOM and meet crop N needs. The farm has remained productive and profitable for over 30 years with no sign of soil depletion.

Conservation Buffers, Wildlife Habitat, and Biodiversity in Organic Systems

Natural areas, native plant communities, conservation buffers, and habitat plantings for wildlife and beneficial organisms contribute to the biodiversity and ecological balance essential for successful organic production. They provide habitat for pollinators and natural enemies of crop pests, hinder the spread of pests and pathogens among fields, reduce wind and water erosion, ameliorate cropland microclimates, provide shade and shelter for livestock and farm workers, protect water quality by intercepting nutrient- and sediment-laden runoff and holding nutrients against leaching, build soil health, and sequester carbon.

Nearly three-quarters of organic farmers maintain perennial conservation plantings, including buffer strips or border rows (54 percent), hedgerows, windbreaks or shelterbelts (35 percent), wildflower strips (17 percent) and natural areas such as woodland or prairie (7 percent), with 39 percent using two or more of these practices.[145] Most plantings covered 1 to 10 acres and ranged from 0.1 acres to hundreds of acres depending on the scale of the operation.

Conservation buffers play another vital role in organic systems: protecting organic crops, livestock, and grazing lands from contamination by pesticides, GMO pollen, or other NOP-prohibited substances in drift or runoff. Table 9 outlines the multiple uses of perennial conservation plantings in organic systems in relation to NRCS practices.

Table 9. Conservation buffers in organic systems and relationship with NRCS practices.

Organic Conservation Activity	Complete Coverage in Existing CPS	Partial Coverage in Existing CPS	Topics in Existing CPS	New Criteria for Organic Buffer Plantings
Wildlife and beneficial habitat plantings	Yes, multiple practices	N/A	Beneficial and wildlife habitat, native plant communities, etc.	Must use organic seed and planting stock if available.
Plantings to intercept or divert runoff with NOP-	No	Diversion (362), Grassed Waterway (412), etc.	Managing runoff to prevent erosion.	Strategically place diversions along boundary between organic and

[145] Snyder et al., *supra* note 10.

Organic Conservation Activity	Complete Coverage in Existing CPS	Partial Coverage in Existing CPS	Topics in Existing CPS	New Criteria for Organic Buffer Plantings
prohibited substances				nonorganic production areas.
Plantings to intercept airborne NOP-prohibited substances	No	Windbreak/ Shelterbelt (380), Riparian Forest Buffer (391), etc.	Provide shelter; protect surface waters from nutrients, sediment, and pathogens.	Strategically place plantings along boundary between organic and nonorganic production areas.
Wild crop harvesting	No	Forest Farming (379)		Harvest must not deplete the plant community.

NOP § 205.202 land requirements include effective buffer zones between organic production areas and neighboring areas under nonorganic management:

> *"Any field or farm parcel from which harvested crops are intended to be sold, labeled, or represented as "organic," must … have distinct, defined boundaries and buffer zones such as runoff diversions to prevent the unintended application of a prohibited substance to the crop or contact with a prohibited substance applied to adjoining land that is not under organic management."*

NOP § 205.2 defines "buffer zone" as:

> *"An area located between a certified production operation or portion of a production operation and an adjacent land area that is not maintained under organic management. A buffer zone must be sufficient in size or other features (e.g., windbreaks or a diversion ditch) to prevent the possibility of unintended contact by prohibited substances applied to adjacent land areas with an area that is part of a certified operation."*

Buffer zones are needed along the property line between the organic farm and a neighboring conventional operation. Split operations that produce or handle both organic and nonorganic products must have buffer zones between organic and nonorganic production areas within the farm. The following NRCS conservation practices, if designed and implemented with adequate width, height, and vegetative density, can provide effective buffer zones against aerial drift of pesticides, GMO pollen, or other airborne substances.

- CPS 327 Conservation Cover
- CPS 380 Windbreak/Shelterbelt
- CPS 391 Riparian Forest Buffer
- CPS 422 Hedgerow
- CPS 612 Tree and Shrub Planting

The following NRCS conservation practices can provide buffer zones against runoff containing soluble fertilizers, soil-applied pesticides or herbicides, or other dissolved or suspended substances.

- CPS 327 Conservation Cover
- CPS 362 Diversion
- CPS 386 Field Border
- CPS 390 Riparian Herbaceous Cover (for potentially contaminated floodwaters)
- CPS 393 Filter Strip
- CPS 412 Grassed Waterway

Some organic producers harvest fruit, nuts, edible mushrooms, medicinal herbs, or other marketable products from woodlands and other natural areas. NOP §§ 205.2 and 205.207 regulations require the producer to manage these areas sustainably and harvest responsibly:

> *"Wild crop: Any plant or portion of a plant that is collected or harvested from a site that is not maintained under cultivation or other agricultural management.*
> *"A wild crop that is intended to be sold, labeled, or represented as organic must be harvested from a designated area that has had no prohibited substance … applied to it for a period of 3 years immediately preceding the harvest of the wild crop.*
> *"A wild crop must be harvested in a manner that ensures that such harvesting or gathering will not be destructive to the environment and will sustain the growth and production of the wild crop."*

Note that any edible crops harvested from a hedgerow, riparian buffer, or other conservation buffer or natural area functioning as a buffer zone and exposed to NOP prohibited substances cannot be labeled or sold as "organic."

Recordkeeping Requirements for NOP-Certified Organic Farmers

The NOP requires certification applicants to submit an organic system plan, including full documentation of:

- Production practices and schedule.
- Inputs list.
- Monitoring procedures.
- Recordkeeping system.
- Practices and physical barriers to prevent contact with prohibited substances.

Conservation Practice Standards Cited in CPS Organic Management and in This Technical Note

CPS 311 Alley Cropping
CPS 316 Animal Mortality Facility
CPS 317 Composting Facility
CPS 327 Conservation Cover
CPS 328 Conservation Crop Rotation
CPS 332 Contour Buffer Strip
CPS 340 Cover Crop
CPS 380 Windbreak/Shelterbelt
CPS 381 Silvopasture

CPS 382 Fence
CPS 386 Field Border
CPS 390 Riparian Herbaceous Cover
CPS 391 Riparian Forest Buffer
CPS 393 Filter Strip
CPS 412 Grassed Waterway
CPS 422 Hedgerow
CPS 512 Pasture and Hay Planting
CPS 528 Prescribed Grazing
CPS 576 Livestock Shelter
CPS 578 Stream Crossing
CPS 585 Stripcropping
CPS 590 Nutrient Management
CPS 592 Feed Management
CPS 595 Pest Management Conservation System
CPS 612 Tree and Shrub Establishment
CPS 614 Watering Facility

Common Abbreviations

ATTRA	Appropriate Technology Transfer for Rural Areas
Bt	Bacillus thuringiensis
CSA	Community Supported Agriculture
COMET	CarbOn Management & Emissions Tool
C:N	Carbon to Nitrogen Ratio
CPS	Conservation Practice Standard
GHG	Greenhouse Gas
GMO	Genetically Modified Organism
IPM	Integrated Pest Management
LGU	Land Grant University
MAOM	Mineral Associated Organic Matter
NCAT	National Center for Appropriate Technology
NPK	Nitrogen, Phosphorus, Potassium
NOP	National Organic Program
OFRF	Organic Farming Research Foundation
OMRI	Organic Materials Review Institution
OSP	Organic System Plan
PAMS	Prevention, Avoidance, Monitoring, Suppression
PTO	Power Take Off
SARE	Sustainable Agriculture Research and Education
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
WIN-PST	Windows Pesticide Screening Tool

Resources

USDA Natural Resources Conservation Service (NRCS)

Tillage Tools and Practices in Organic Farming Systems: Limiting Soil Disturbance to Build Soil Health in Organic Cropland. Includes eight farm stories with details on crop rotations and tillage practices for co-managing soil health and weed pressure. In press.

The National Organic Farming Handbook, 190 H Part 612

Organic Webinars in the Science and Technology Webinar Library

USDA National Organic Program (NOP) Regulations

USDA Sustainable Agriculture Research and Education (SARE) Publications

Manage Weeds on Your Farm: A Guide to Ecological Strategies, by Charles L. Mohler, John R. Teasdale, and Antonio DiTommaso. 2021.

Steel in the Field: A Farmer's Guide to Weed Management Tools, by Greg Bowman. 1997.

Manage Insects on Your Farm: A Guide to Ecological Strategies, by Miguel A. Altieri, Clara I. Nicholls, and Marlene A. Fritz. 2005.

Building Soils for Better Crops: Ecological Management for Healthy Soils, 4th Edition, by Fred Magdoff and Harold Van Es. 2021.

Managing Cover Crops Profitably, 3rd Edition, by Andy Clark. 2007.

Crop Rotations on Organic Farms: A Planning Manual, by Charles L. Mohler and Sue Ellen Johnson, eds. 2009.

Organic Farming Research Foundation (OFRF) Publications

The following publications are available at https://ofrf.org/resources/#publications.

Soil Health and Organic Farming guidebook series and webinars:

- *Building Organic Matter for Healthy Soils: An Overview*
- *Cover Crops: Selection and Management*
- *Nutrient Management for Crops, Soil, and the Environment*
- *Weed Management: An Ecological Approach*
- *Practical Conservation Tillage*
- *Plant Genetics: Plant Breeding and Variety Selection*
- *Water Management and Water Quality*
- *Organic Practices for Climate Mitigation, Adaptation, and Carbon Sequestration*
- *Understanding and Optimizing the Community of Soil Life*
- *Building Healthy Living Soil for Successful Organic Farming in the Southern Region*

- *Reducing Risk through Best Soil Health Management Practices in Organic Crop Production*
- *An Organic Approach to Increasing Resilience*

Courses and webinars:
- *Basics of Organic Farming*
- *Soil Health Strategies for the Southern Region*
- *Link to webinars based on the first nine soil health topics listed above.*

2022 National Organic Research Agenda. A report on the 2020 OFRF survey of more than 1,000 certified organic farmers and 71 transitioning farmers across the U.S. to identify organic farmers' research priorities and technical assistance needs.

Organic Farming for Bees: Conservation of Native Crop Pollinators in Organic Farming Systems

Avoiding Pesticide Drift Impacts on Organic Farms

National Center for Appropriate Technology – Appropriate Technology Transfer for Rural Areas (ATTRA) Publications

Publications on a wide range of topics in organic production, conservation, and marketing are available at https://attra.ncat.org/organic-farming/.

Land Grant University and Other Resources

Physical Weed Control Forum. A University of Maine and Michigan State University project that connects farmers, researchers, and manufacturers working to improve weed control in field and horticultural crops through advanced cultivation tools and techniques.

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