

Soil Health and Organic Farming

Cover Crops: Selection and Management

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**ORGANIC
FARMING**
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SOIL HEALTH AND ORGANIC FARMING

COVER CROPS: SELECTION AND MANAGEMENT

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

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Introduction

Over the past 30 years, cover cropping has emerged as a key soil health and resource conservation practice for annual crop production. Cover crops protect the soil surface from erosion and compaction, add organic matter, fix nitrogen (N), conserve and recycle nutrients, suppress weeds, and contribute to biological control of other pests. While only 10.3 million (~4%) of the 278 million acres of annual cropland across the US were planted with cover crops in 2012 (USDA NASS, 2014), national surveys of US farmers have documented a steady increase in cover cropping since then (USDA, SARE, 2016).

Living vegetation is the primary source of “food” (organic energy compounds) for the soil life (soil food web), and all terrestrial life forms ultimately depend on the mutualistic relationship between plants and soil. In addition, living plants provide the only practical means through which excess atmospheric carbon dioxide (CO₂) can be recycled (sequestered) back into the soil to stabilize our climate. Truly sustainable agriculture must maintain effective vegetative cover of the soil, even when the field is not in production. Hence, the National Organic Standards require certified organic producers to include cover crops in their crop rotations.

The Natural Resources Conservation Service has developed four basic principles of soil health management (USDA NRCS, Accessed 2017) in which cover crops play key roles.

- Keep the soil covered as much as possible.
 - Year-round living vegetation or residue cover protects the soil from rain, wind, and sun, prevents erosion and crusting, adds organic matter, and feeds soil life.

Truly sustainable agriculture must maintain effective vegetative cover of the soil, even when the field is not in production. Hence, the National Organic Standards require certified organic producers to include cover crops in their crop rotations.



Figure 1. Plants growing in cover crop residue, Mark Schonbeck

- Timely cover crop planting after harvest can largely eliminate bare fallow, which might otherwise exceed six months per year in a corn-soybean rotation.

■ Keep living roots growing throughout the year.

- Rhizodeposition (root exudates and fine root sloughing) provides a continuous supply of food for beneficial soil microbes—the more living roots, the better.
- The deep, extensive root systems of mature cover crops enhance drainage and aeration, and bring organic matter and soil life deeper into the soil profile.
- Cover crop roots recover leached nutrients, thereby protecting water quality and enhancing fertility for the subsequent crop that is planted.

■ Manage more by disturbing soil less.

- Cover crops reduce chemical soil disturbances by lessening the need for soluble fertilizers, pesticides, and herbicides.
- Cover crops reduce biological disturbance by supporting soil life year round.
- Cover crops can reduce physical soil disturbances by suppressing weeds and lessening the need for tillage and cultivation.

■ Diversify soil biota with plant diversity

- Adding cover crops to an existing rotation enhances diversity of plant species, and thereby the community of root-associated soil organisms.
- Cover crop mixes further improve diversity.

Many information sheets, webinars, and other resources on cover crops are now available to help producers implement this vital practice. Examples include the SARE manual *Managing Cover Crops Profitably*, the SARE website cover crop topic room, the NRCS Soil Health Initiative, and the Midwest Cover Crop Council (Table 1). Much of this information is relevant to all farming systems. However, additional information specific to organic production is needed for the following reasons:

- Organic farmers rely more heavily than non-organic farmers on cover crops to provide and manage crop nutrients, especially nitrogen (N).
- Organic farmers rely more heavily on cover crops for weed and pest management.
- Without the use of herbicides, organic farmers rely on mechanical methods or seasonal weather shifts (such as killing freezes) to terminate cover crops.
- At the same time, the absence of herbicides from crop rotations enhances flexibility in cover crop species selection, planting date, interseeding, and crop rotation design.
- Long term organic management can modify soil nutrient dynamics, so that production crop responses to a preceding cover crop may differ from conventional systems.

Nationwide surveys of organic farmers in 2007 and 2015 identified soil health and cover crops as top re-search priorities (Sooby et al., 2007; Jerkins and Ory, 2016). Between 2002 and 2014, some 38% of projects funded through the USDA Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) evaluated cover cropping practices in relation to various aspects of soil health including organic matter, tillage, reduced tillage, soil biology, and nutrient cycling (Schonbeck, Jerkins, and Ory, 2016).

Challenges in Selecting and Managing Cover Crops in Organic Systems

The benefits of cover crops are directly related to the quantity and quality of biomass generated. A cover crop that is allowed to grow to several tons per acre aboveground biomass and is terminated at full bloom adds a lot more organic matter and supports more biological activity than one that is terminated even a few weeks earlier (Drinkwater, 2011; Spargo, 2012). On the other hand, an over-mature cover crop may set viable seeds which could create a potential weed problem, or leave high carbon-to-nitrogen (C:N) ratios that reduce N availability to the following crop (N tie-up).

Timely planting to ensure rapid early establishment of the cover crop is essential for erosion and weed control, and enhances final biomass and N fixation.

An all-legume cover crop may break down too rapidly, releasing a large pulse of N that may leach to groundwater or stimulate weed growth (Heilig and Hill, 2014; Teasdale, 2012), while an all-grass cover crop leaves persistent residues that suppress weeds but can tie up N or hamper field operations. Cover crop mixtures of two or more species are gaining popularity for their potential to provide a wider range of soil health and other benefits (SARE, 2016). However, finding the right mixture for one's local region and production system can be challenging (Barbercheck et al., 2014).

Timely planting to ensure rapid early establishment of the cover crop is essential for erosion and weed control, and enhances final biomass and N fixation. Optimum planting dates and rates for a given cover crop can vary with climate and seasonal weather fluctuations, cover cropping objectives, and the species and planting date of the subsequent crop. Timely cover crop planting can be challenging to schedule in relation to the preceding crop harvest, other field operations, and availability of labor.

Dryland farmers in limited-rainfall regions face challenges related to soil moisture and cover cropping. In the long run, high biomass cover crops can enhance the soil's capacity to hold plant-available moisture. However; in the short term, a vigorous cover crop consumes water and can leave less moisture for the following production crop than would the traditional fallow year.

Additional challenges for organic systems in all regions may include:

- Determining how the cover crop can be terminated without herbicides or excessive tillage that would compromise soil health benefits.

- Selecting cover crop species and methods that support organic nutrient and weed management.
- Obtaining cover crop decision tools that address organic growers' needs in specific regions.
- Estimating plant-available N from cover crops. Formulae developed for conventional production may not account adequately for nutrient dynamics in organically managed soils.

Selecting and Using Cover Crops for Soil Health in Organic Production: Some Tips and Information Resources

The following factors should be considered when choosing the best cover crops and management practices:

- Region, climate, frost dates, and hardiness zone.
- Soil type and conditions, including texture, depth, drainage, mineralogy, tilth, organic matter.
- Goals and priorities for the cover crop (desired functions and benefits).
- Rotation niches (non-production periods) into which the cover crop must fit:
 - Season – early spring, frost-free/summer, fall, over winter.
 - Duration of window - days until expected fall frost or until desired planting date for the following production crop.
- Preceding production crop – impacts on soil, opportunities for pre-harvest interseeding.
- Production crop to follow cover crop – nutrient, pest management, and other needs.
- Availability and cost of organic cover crop seed (untreated non GMO if organic is not available).
- Availability of locally or regionally adapted cultivars or strains of the cover crop.
- Available tools and equipment for cover crop planting and management.
- Attributes of cover crop species:
 - Total biomass production
 - N fixation or recovery; C:N ratio
 - Rooting depth and architecture (taproot, fibrous root, etc)
 - Hardiness to frost or freeze, drought, heat, etc.
 - Life cycle, expected date of maturity (full height, flowering)

Don't let this long list deter you from cover cropping for soil health. For example, winter cereal rye makes a good fall-planted cover crop just about everywhere in the US, and a rye monoculture is far better than leav-

ing the soil bare over winter. Any of the following approaches can lead to effective cover cropping for soil health:

- *If you are just getting started with cover crops, start simple.* Select and plant single-species cover crops appropriate to season and duration of each niche (non-production period) in your rotation. Observe and document how well they meet your goals and fine-tune the practice year to year. Experiment on a small scale with new cover crop species or a simple mix such as a grass with a legume.
- *Use decision support tools or other information sheets designed for your region to help select a cover crop or mixture.* Again, observe its performance and fine-tune your cover cropping system accordingly year to year.
- *Design and improve your own cover cropping system.* Use the following outlines to help you select cover crops and management practices for your particular soils, microclimates, crop mixes, and available resources.

Selecting the Cover Crop

Step 1: Identify your priority soil health and other goals for growing cover crops. See Table 1 for an outline of cover crop characteristics and suggested cover crop species selections to address each goal.

Table 1. Cover cropping goals, desired characteristics and suggested cover crop species.		
Goal	Cover crop characteristics	Suggested cover crop selections
Protect the soil surface from erosion, compaction, and organic matter oxidation	Rapid establishment and canopy closure, persistent residues.	Buckwheat, cowpea, radish, other crucifers (canopy), cereal grains, millets, sorghum-sudan-grass (residues).
Add organic matter, sequester carbon (C)	High biomass, extensive deep and fibrous root systems, moderate to high C:N, perennial or long-season annual.	Sorghum-sudangrass, millets, sunflower, cereal grains, perennial grass or grass-legume sod
Feed soil life: enhance activity, diversity, and health of the soil food web	Diversity of cover crops including high and low C:N species, and hosts for mycorrhizal fungi (grasses and legumes)	Combine grasses, legumes, and crucifer or other forbs

Table 1. Cont.

Goal	Cover crop characteristics	Suggested cover crop selections
Improve topsoil tilth	Extensive fibrous root systems	Cereal grains, ryegrass, millets, other grasses, buckwheat.
Relieve subsurface hardpan, open soil profile	Deep taproot or deep, robust fibrous root.	Radish, canola, alfalfa, red clover, sweetclover (taproot); sorghum-sudangrass, pearl millet (fibrous roots).
Fix nitrogen (N), enhance plant available nitrogen (PAN) for subsequent crop.	Symbiotic N fixation (legumes), low C:N ratio (legumes, crucifers), N-demand to stimulate N fixation (crucifers)	Clovers, vetches, bell bean, field peas, cowpea, soybean, etc. Radish, mustard, etc. (not before crucifer vegetables)
Maximize total N fixation and provide season-long, slow-release PAN.	N fixing crops to comprise 30 - 50% of stand, with remainder comprised of N-demanding crops; moderate overall C:N ratio.	Cereal grains + vetch, pea, or clover; millets or sorghum-sudan + cowpea, soybean, or tropical legume. Add crucifer or other forbs (optional).
Absorb excess PAN to prevent N leaching and denitrification losses	Heavy N feeders.	Sorghum-sudangrass, rye, other cereal grains, radish, other crucifers
Retrieve N and other nutrients from deep in the soil profile	Deep rooted heavy N feeders for N, capacity to retrieve and mobilize soil P, K, and micronutrients.	Radish, canola (NPK), sorghum-sudan, rye, other grasses (N, K), legumes and buckwheat (P).
Suppress weeds	Rapid establishment and canopy closure, persistent residues	Buckwheat, cowpea, crucifers (canopy); cereal grains, other grasses (residue)
Disrupt life cycles of plant pests (insect, nematode, etc.), plant pathogens, and weeds	Cover crops that suppress or do not host target pests, that are from different plant family from production crops, and that vary type and timing of field operations.	Varies with production crop mix. Perennial sod break for two or more years can be especially effective.
Enhance biological pest control by providing food and habitat for natural enemies of insect pests	Flowers with abundant pollen and nectar and shallow structure to allow access by tiny insects; extrafloral nectaries; ground coverage by living vegetation or residues.	Buckwheat, phacelia, sunflower, vetches, cowpeas, clovers, some grasses (nectar, pollen); any cover crop left on surface after termination or frost-kill (habitat)

Step 2. Identify the cover crop niches in your crop rotation, including season and target planting and termination dates. Map out a timeline to help plan and select cover crops. See Table 2 for suggested cover crops for different seasons and niches.

Table 2. Suggested cover crop species for different niches in the crop rotation.	
Timing of cover crop	Suggested cover crop selections
Fall planted winter cover crop ahead of warm season crop	Cereal grains, winter annual legumes and crucifers adapted to your USDA hardiness zone
Early spring cover ahead of mid-late summer production crop	Spring oats, barley, fava bean, vetches, field peas, crimson or berseem clover, mustards, etc.
Early summer covers (after spring frost date)	Non-GMO forage soybean, buckwheat, millets.
Mid-late summer covers	Sudangrass, sorghum-sudan hybrids, buckwheat, sunflower, millets, soybean, cowpea, sunnhemp, tropical legumes
Late summer-fall planted covers to winter-kill ahead of early spring production crop	Cool season grasses, legumes, crucifers that will winter-kill in your zone.
Short time niches during frost-free season	Buckwheat, Japanese millet, cowpea
Longer-season crops for hot weather	Sudangrass, sorghum-sudan hybrid, or pearl millet with cowpea, sunnhemp, or tropical legume. Mow and let regrow.

Step 3. Consider other challenges and opportunities related to your climate, soils, crop rotation, and production system. For example, when land resources and cropping schedules permit, consider a perennial sod break in the rotation to enhance soil health and fertility, and reduce weed populations. Perennial sod covers include warm and/or cool season pasture grasses combined with alfalfa, perennial clovers, or other perennial legumes, and optionally other forbs. Regionally adapted pasture seeding mixes can serve this purpose well. Crop-livestock integrated systems that implement rotational grazing of the perennial sod can enhance soil health and fertility benefits.

Certain cover crops may be especially well adapted to certain soil fertility or moisture constraints, including:

- Pearl millet, cowpea, sunnhemp, and sorghum-sudangrass tolerate hot, dry conditions.
- Japanese millet, oats, and alsike clover tolerate cool, wet, slow-draining soils.
- Sunnhemp, pearl millet, cowpea, and buckwheat tolerate, and help remedy, low soil fertility.

- Legumes are a good choice where plant-available soil N is low..
- Oats, rye, hairy vetch, cowpea, sunnhemp, and buckwheat tolerate low (acidic) soil pH.
- Barley tolerates salinity and high (alkaline) pH.

Researchers and farmers have also observed some “rotation effects” in which certain cover crops seem to enhance the performance of certain production crops planted after the cover. Examples include:

- Soybean, a strong N fixer, benefits from winter rye (high C:N, weed suppressor).
- Spring spinach thrives after fall tillage radish or oilseed radish (soil biology effects).
- Corn thrives after alfalfa or red clover sod, often needing no additional N.
- Hairy vetch or rye + vetch covers have been reported to enhance tomato crops.

Watch for other beneficial rotation effects or sequences in your farming operation, or reported in farmer publications from your region.

Step 4. Choose your cover crop(s). Use information resources for your region (Table 3, [page 15](#)) to further assist you in making the best possible selections. Consider using locally produced seed and locally adapted varieties or strains of the cover crop. For example, some lines of hairy vetch and fava bean are much more winter-hardy than others. In addition, hairy vetch cultivars may vary in flowering date and ease of roll-crimp termination.

Finally, be willing to think outside the box. Just because a particular plant species is not mentioned here and is not on the NRCS or Cover Crop Council species lists, it does not mean it cannot build soil health and perform other vital functions for your farm. Several innovative farmers have even reported success with using common annual weeds as cover crops. However, be sure to avoid noxious, invasive-exotic, or difficult-to-control species.



Figure 2. Roller crimper used to terminate cover crop, Mark Schonbeck



*Figure 3. Crimson clover cover crop,
Mark Schonbeck*

When in doubt about a particular species, check your state's noxious weeds / invasive plants lists. Some of these invasive exotic plants can directly interfere with the indigenous soil food web in your region.

Selecting and Fine-tuning a Cover Crop Mix or Cocktail

Mixtures of two or more dissimilar species can perform more functions and may enhance soil health to a greater degree than a single species cover crop (Hooks et al., 2015). The most widely used mixtures consist of grasses and legumes with similar seasonal requirements. Winter rye and other cereal grains generate high biomass, scavenge N, suppress weeds, and leave persistent residues, but may tie up soil N. Pure stands of legumes such as hairy vetch or Austrian winter pea can be so rich in N that their termination can leach N or stimulate the growth of pig-weeds, lambsquarters, and other N-responder weeds (Grossman, 2012). Grass-legume mixtures provide a balanced C:N ratio and slow-release N to the following crop (Teasdale, 2012), and the grass component can enhance legume N fixation by consuming soluble soil N (Drinkwater, 2011) and providing support for viny legumes like hairy vetch (Andrews and Sullivan, 2010).

Rye and vetch make an excellent winter cover crop for many regions (Teasdale, 2012) and their complementary architecture can enhance weed suppression over either species alone (Schonbeck et al, 1993). Other grass-legume bicultures include: oats + Austrian or other field peas for early spring or late summer planting; sorghum-sudan + cow-pea for summer, and pearl millet + sunnhemp to restore poor, droughty soils in summer. Grass-legume mixes may include several species (e.g., rye, oats, winter pea, vetch, and crimson clover) to enhance resilience to variations in soil fertility and weather extremes.

In more recent years, researchers and conservationists have developed multispecies mixes that include three or more plant families or “functional groups”. A common “trio” is grass, legume, and crucifer. Examples include oats, peas, and mustard in spring; tillage radish with summer or cool season grass and legume in late summer; or fall planted rye, winter pea, and canola for a winter cover hardy to Zone 7. Additional plant families may be represented by buckwheat, sunflower, phacelia, or other crops, and some cover crop cocktails include 10 or more species from multiple plant families. Such high-diversity cocktails have been reported to improve soil fertility and moisture capacity in dryland production in North Dakota, and to support maximum corn grain yields without added fertilizer N in Ohio (Archuleta, 2012). Based on these observations, cover crop enhancements offered through the NRCS Conservation Stewardship Program for 2017 require a minimum of three or four species planted together (USDS NRCS, 2016).

However, cover crop mixes can be challenging to manage for the following reasons:

- Planting several cover crop species with different seed sizes, shapes, and optimum seeding depths entails logistical challenges and may require equipment modifications.
- Increased costs of the mix (seed, equipment, labor) may exceed direct short-term dollar value of additional benefits.
- Faster-growing components (e.g., buckwheat, crucifers, cereal grains) may outcompete or suppress others (e.g., legumes), so that the functions of the latter are compromised or lost.
- Weather variations and soil conditions can greatly affect interactions among components; for example, nonlegumes will outcompete legumes when soil PAN is high.
- One or more components may harbor pests or diseases of the following production crop.

Effective cover crop cocktails feature compatible and complementary interactions among components. Mixing crops with different rooting depths; nutrient, light, and moisture needs; below- and above-ground architecture; and seasonal life cycles can enhance success. For example, clovers can establish in the shade of taller species like oats or sorghum-sudan if the grasses are not planted too heavily, then grow vigorously when the taller grass is removed by mowing, grazing, or frost-kill (Drinkwater and Buckley, 2010). Combining warm and cool season species (e.g., millet, soybean, oats, radish) in a late summer planting, or semi-hardy and winter-hardy species (e.g., oats, berseem clover, rye, hairy vetch) in fall can extend the period of active growth and N fixation when the more tender species freeze-kill and the hardier ones take over.



Figure 4. Cowpea cover crop, Mark Schonbeck

However, combining crops with *very* different seasonal requirements (e.g. sorghum-sudan + rye, or cowpea + hairy vetch) may be less effective.

Guidelines for determining seeding rates in mixtures vary widely. Dividing recommended rates for each crop by the number of crops in the mix may allow the most competitive species to suppress others. In grass-legume bicultures, common practice is to cut the grass seeding rate by half or more, while planting the legume at 60-100% of full rate. Lower individual seeding rates have been recommended for high-diversity cocktails for soil health (Archuleta, 2012), while higher rates may be warranted for weed suppression.

Because of the complexity of species interactions and environmental factors, no formulae can be given for the “right” mix. To develop a mixture for your farm:

- Define priority objectives, season, and environmental factors as outlined above.
- Select two or more species, suited to your soil, climate, and rotation, to meet your goals.
- Set seeding rates based on past experience and/or recommendations for your region.
 - Sow cereal grains, buckwheat, and crucifers at lower % of full rate than legumes and small-seeded species.
 - Aim for total equivalent rate near 100%, (e.g., rye, radish, and pea at 20%, 30%, and 50% of their recommended pure-stand rates, respectively)
 - Increase total equivalent rate above 100% for later-than-optimal planting or when weed suppression is a priority.
- Observe outcomes and adjust the mix next time.

Planting and Managing the Cover Crop

Cover crops are not as fussy as most production crops. However, good planting techniques and favorable soil conditions are critical for optimum results. Some tips include:

- Remedy severe hardpan, extreme pH, or critically low nutrients before planting.
- Follow regional guidelines for best seeding dates, rates, depths, and methods.
- Drill seed, or broadcast (increase rates ~1.5X) and work in to desired depth.
- Apply manure or other organic nutrient sources based on soil test to maximize biomass.
- Irrigate newly-seeded cover crop if conditions are dry.

Cover crop termination for production crop planting can pose a special challenge for organic growers, since the soil disturbance of tilling-in a cover crop can compromise some of the tilth-enhancing, organic matter, weed control, and carbon sequestration benefits of the cover crop itself. No-till cover crop termination and production crop planting can work in organic systems where weed populations are low, but may not be feasible when weed pressure is heavy or dominated by invasive perennial species. However, sound crop rotations with effective use of cover crops can build soil health even in the context of routine tillage.

Integrating Cover Crops with Other Soil Health Practices

Cover crops work synergistically with other organic inputs and practices to build and maintain a vibrant, diverse, and well-fed community of soil life (soil food web). Depending on soil conditions, you may need to replenish the organisms themselves (good finished compost can serve this purpose) and provide a “balanced diet” of diverse organic residues varying from low to high C:N ratio. A few tips include:

- Use cover crops *and* compost together in your cropping system to rebuild and maintain soil health and fertility.
- Balance low C:N organic inputs with higher C:N cover crops, or vice versa.
- Apply manure at time of cover crop planting if warranted by soil test.
- Add cover crops to an intensive cropping system to reduce amount of compost needed.

Financial and Technical Assistance for Cover Cropping

The USDA Natural Resources Conservation Service (NRCS) offers cost-share for the cover cropping practice through its working lands conservation programs, the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP). The Organic Initiative within EQIP emphasizes cover cropping, crop rotation, and other practices especially suited to organic production systems. NRCS also offers conservation planning technical assistance, which may include advice and help in choosing the best cover crops, planting dates, and management practices for your region.

Some State departments of agriculture or natural resource conservation also offer cost-share for cover cropping practices. For example, a Maryland Department of Agriculture cost share brought an additional 478,000 acres into cover cropping in MD in 2014 (Hooks et al., 2015).

Inquire at your Soil and Water Conservation District and NRCS office about federal and state level sources of financial and technical assistance for cover cropping.

See Table 3, [page 15](#), for some nationwide and regional information resources on cover crops for soil health.

For more information on using cover crops for soil-enhancing organic nutrient management, see the companion report, *Nutrient Management: Crops, Soil, and the Environment*. For more on using cover crops for soil-friendly organic weed management, see *Weed Management: An Ecological Approach*. For more on reduced tillage cover crop management, see *Practical Conservation Tillage*. For more on the relationship between crop genetics (including cover crops) and soil health, see *Plant Genetics: Plant Breeding and Variety Selection*.

Table 3. Information Resources and Tools for Selecting and Managing Cover Crops for Soil Health

Nationwide Resources

1. **Cover Cropping in Organic Farming Systems** <http://articles.extension.org/pages/59454/cover-cropping-in-organic-farming-systems>. Dozens of articles, video clips, and webinars on cover cropping for organic systems, developed by the eOrganic Community of Practice and posted on the Extension Website.
2. **ATTRA: a National Sustainable Agriculture Assistance Program** offered through the National Center for Appropriate Technology. <https://attra.ncat.org/>. Cover crop resources include:
 - a. *Overview of Cover Crops and Green Manures* (P. Sullivan, 2003) <https://attra.ncat.org/attra-pub/summaries/summary.php?pub=288>.
 - b. *Cover Crop (340) in Organic Systems* (R. Dufour, S. Brown, B. Howell, and C. Sendack, 2013). NRCS cover crop conservation practice for organic systems. <https://attra.ncat.org/attra-pub/summaries/summary.php?pub=486>.
3. **Managing Cover Crop Profitably**, 3rd edition*, published by USDA Sustainable Agriculture Research and Education (SARE). Available at <http://www.sare.org/Learning-Center/Books>.
4. **NRCS Soil Health Initiative*** <https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/>
 - a. Soil Health Management (four principles): <https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/mgmt/>
 - b. Page with cover crop links: <https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/>.
 - c. Cover crop termination guidelines worked out among NRCS, FSA, RMA: <https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/plantmaterials/technical/publications/?cid=stelprdb1077238>

5. **SARE Cover Crop Topic Room*** <http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops>.
 - a. Ohio State University Extension bulletin Sustainable Crop Rotations with Cover Crops at: <http://www.sare.org/Learning-Center/SARE-Project-Products/North-Central-SARE-Project-Products/Sustainable-Crop-Rotations-with-Cover-Crops>.
 - b. For organic systems: <http://www.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/Cover-Crops-and-No-Till-Management-for-Organic-Systems>.
 - c. Cover crop survey results (past four years): <http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/Cover-Crop-Surveys>.
6. **National Sustainable Agriculture Information Service, Soils and Compost page** <https://attra.ncat.org/soils.html>. Videos and information sheets on cover crops including applications for hot climates, reduced tillage, orchard floor management, and small scale intensive operations.

Western Region

1. **Estimating Plant-Available Nitrogen Release from Cover Crops** (D.M. Sullivan and N. D. Andrews, 2012). Pacific Northwest Extension bulletin 636. Step by step guide. <https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/pnw636.pdf>.
2. **Organic Fertilizer and Cover Crop Calculators** for Pacific Northwest regions west and east of the Cascades. <http://smallfarms.oregonstate.edu/node/54>.

North Central Region

1. **Risk Management Guide for Organic Producers** (K. Moncada and C. Sheaffer, 2010, University of Minnesota, 300 pp) *Chapter 13, Winter Cover Crops*, offers research-based cover crop selection and management recommendations for upper Midwest. Chapter 14, *Alternative Crops* discusses sunflower, sorghum, amaranth, millets, buckwheat, field peas, triticale, and several other alternative crops grown for soil improvement and other agro-ecosystem services as well as livestock feed and other production goals. <http://organicriskmanagement.umn.edu/>.

2. **The Role of Cover Crops in Organic Transition Strategies Webinar** (B. McSpadden-Gardner, Ohio State University). <http://articles.extension.org/pages/62450/the-role-of-cover-crops-in-organic-transition-strategies-webinar>.
3. **Midwest Cover Crop Council*** <http://mccc.msu.edu/>. **Cover crop selector tools** for row crops (most of Midwest), vegetable crops (Michigan only), and research summaries.

Northeast Region

1. **Crop Rotations on Organic Farms**, Charles A. Mohler and Sue Ellen Johnson, eds. Available at <http://www.sare.org/Learning-Center/Books>. Crop rotations developed for grain, vegetable, and mixed cropping systems by organic producers across the Northeast region (Maryland to Maine), including extensive and innovative uses for cover crops.
2. **Using Cover Crop Mixtures to Achieve Multiple Goals on the Farm** (Mary Barbercheck et al., Penn State, 2014). Webinar, integrating weed management with other cover crop goals. <http://articles.extension.org/pages/71186/using-cover-crop-mixtures-to-achieve-multiple-goals-on-the-farm-webinar>.
3. **Making the Most of Mixtures: Considerations for Winter Cover Crops in Temperate Climates**. (Charles White et al., Pennsylvania State University, 2016). In-depth guidelines for developing the best mix. <http://articles.extension.org/pages/72973/making-the-most-of-mixtures:-considerations-for-winter-cover-crops-in-temperate-climates>.
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5. **Special Supplement on Legumes as Cover Crops**. *The Natural Farmer*, Summer, 2011. <http://www.nofa.org/tnf/Summer2011B.pdf>. Emphasis on legume cover crops for N fixation.

6. **Cover Crops: What a difference a few weeks make!*** Planting and termination dates for cover crops in upstate New York. <http://www.hort.cornell.edu/extension/organic/ocs/reports/Cover%20Crops%20Planting%20and%20Termination.pdf>.
7. **Northeast Cover Crop Council (NECCC).*** Established through a 2016 Northeast SARE Professional Development Program grant, the NECCC aims to develop, deliver and provide technical support for **cover crop selector tools** based on that developed by the Midwest Cover Crop Council, adapted for each of the states in the Northeast region. Project outline, annual reports, and contact info for project leader Katherine Tully at https://mysare.sare.org/sare_project/ENE16-144/. 2016 Tri-Societies Conference poster at <https://scisoc.confex.com/crops/2016am/webprogram/Paper100552.html>.

Southern Region

1. **Virginia Association for Biological Farming.** Four information sheets on cover crops, including *Cover Crops for All Seasons* with descriptions, selection criteria, and management information for 34 cover crop species based on ORG-funded research and grower experiences at several sites across Virginia. <http://vabf.org/information-sheets/>
2. **Cover Crops for Vegetable Growers.** Presentation by Virginia vegetable farmer and author Pam Dawling, 113 slides, 2016. Excellent region-specific (central VA) information on selection and management of cover crops and mixtures for a wide range of rotation niches. Available on Slide Share (www.slideshare.net, search for Pam Dawling), and at <http://www.sustainablemarketfarming.com/category/slide-shows/>.
3. **Increasing Soil Fertility and Health Through Cover Crops** (Julie Grossman, 2012). Carolina Organic Commodities and Livestock Conference 2012: Selected Live Broadcasts. <http://articles.extension.org/pages/61970/carolina-organic-commodities-and-livestock-conference-2012:-selected-live-broadcasts>.
4. **Cover Crop Benefits for South Florida Commercial Vegetable Producers*** (Q. Wang, Y. Li, E. A. Hanlon, W. Klassen, T. Olczyk, and I. V. Ezenwa, University of Florida, 2015). <http://edis.ifas.ufl.edu/ss461>.

5. **Southern Cover Crop Conference.*** Videos and fact sheets from the Southern SARE conference in Goldsboro, North Carolina in 2016. <http://www.southernsare.org/Events/Southern-Cover-Crop-Conference>.

*These resources are not specifically addressed to organic systems and may include reference to materials or practices not allowed under USDA Organic Standards. However, much of the information is relevant to all production systems.

Current Science on Cover Cropping for Organic Systems: An Analysis of USDA OREI and ORG Funded Research from 2002 - 2016

Multiple studies have confirmed the vital role that cover crops play in rebuilding and sustaining soil health (Delate et al., 2015; Hooks et al., 2015; Sheaffer et al., 2007; Tavantzis et al., 2012). For example, research in North Carolina documented the key role that fine roots of hairy vetch, winter pea, and crimson clover play in both soil health and plant nutrition (Hu et al., 2015). Comprising some 70% of below-ground biomass, the fine roots of these cover crops made a major contribution to soil carbon (C) as well as plant-available N.

Cover crops and compost or other organic soil amendments work together to enhance soil health and fertility (Delate et al., 2015; Hooks et al., 2015; Tavantzis et al., 2012). Heavy reliance on low C:N organic fertility sources, such as poultry litter, can result in a net loss of soil organic matter and increased N leaching (Li et al., 2009; Wander et al., 2016), while soils managed with diverse cover crops and other organic inputs varying from low to high C:N ratio become healthier, with higher active and total organic matter and improved nutrient cycling (Jackson and Bowles, 2013; Bowles et al., 2015).

Cover Crop Cocktails

The complementary benefits of high-carbon grass and high-nitrogen legume cover crops have been well established through research and farmer experience, and grass-legume bicultures are widely used by organic producers. Grass-legume mixtures can enhance soil health outcomes over either alone (Hooks et al., 2015) and reduce the risk of N leaching and denitrification into the powerful greenhouse gas nitrous oxide (N₂O) (Baas et al., 2015). Additional benefits from enhanced plant and microbial biodiversity might be expected from multi-species cover crop “cocktails,” now widely promoted in federal conservation programs (USDA NRCS 2016, USDA NRCS undated). For example, summer smother crops of tef or sorghum-sudangrass grown in mixture with forage soybean and sunflower had higher biomass and weed suppression than the grass alone in trials in OH (Cardina et al., 2006). However, the additional benefits offered by multi-species mixes versus one- or two-species cover crops are often inconsistent and site-specific (McSpadden-Gardner et al., 2014; Drinkwater and Walter, 2015).

Species selection and seeding rates need to be adapted to climate, soil conditions, recent field history, and production system to obtain the desired balance in the mix. For example, a four-way mix of rye (28 lb/ac),

Austrian winter peas (35 lb/ac), red clover (6 lb/ac) and canola (9 lb/ac) was dominated by rye in northern Pennsylvania, and by canola further south (Barbercheck et al., 2014). In addition, where plant-available nitrogen (PAN) was high at time of cover crop planting, legume biomass was negligible (Ibid.). Mixtures that rapidly established fall cover and included a winter hardy grass prevented erosion, suppressed weeds, and retained nutrients, but fixed little additional N; lower seeding rates for the winter grass and managing for low PAN at time of cover crop planting might enhance N fixation (Kaye et al., 2016). The research team recommended designing cover crop mixes for specific priorities rather than maximum species richness, and is now working with farmers to “farm-tune” cover crop mixtures and elucidate N dynamics related to seeding ratios, climate, and existing soil PAN levels (Kaye, 2016).

In upstate New York, a similar tradeoff between N fixing capacity and weed suppressiveness was observed in mixtures planted in mid-summer (Drinkwater and Buckley, 2010). Buckwheat showed the greatest competitiveness toward both weeds and legume components of the cover crop, followed by sorghum-sudangrass, Japanese millet, and flax in that order. Surprisingly, genetic diversity *within* a cover crop species yielded more consistent benefits than multispecies cocktails (Drinkwater and Walter, 2015). In multi-site trials over two years, mixes of two or more cultivars of a cover crop species significantly and consistently enhanced weed suppression over a single cultivar. This trend held true for all six cover crops evaluated: hairy vetch, winter pea, crimson clover, wheat, rye, and ryegrass.



Figure 5. Cover crop mixture, Mark Schonbeck

Selecting and Managing Cover Crops for Colder Regions: North-Central and Northeast

Colder regions with short growing seasons present challenges in integrating cover crops into annual crop rotations. For example, because of short duration of active growth and sometimes winterkill, hairy vetch developed insufficient biomass to provide N or suppress weeds for subsequent corn crops in North Dakota, Michigan, Iowa, Wisconsin, Minnesota, and Pennsylvania (Delate, 2013, Sheaffer et al., 2007). Notably, local land races of hairy vetch survived the MN winter much better than purchased seed produced further south (Moncada and Sheaffer, 2010).

Several cover crops have performed well in upstate NY, including:

- Buckwheat planted in June or July (aboveground biomass 3,000 lb/ac in 40 days).
- Winter rye and hairy vetch planted by September 15th and terminated late May at 6,000+ lb/ac, oats.
- Forage variety of field pea planted mid-April and grown at least 75 days to reach 6,000 lb/ac, and red clover overseeded into spelt in March and grown until the following May, about 14 months (Cornell, n.d.).

Poor performers in New York include bell beans or soybeans in late summer, and crimson or berseem clovers overseeded into spelt.

In the Great Lakes region (Michigan and western New York), buckwheat and sudangrass must be planted by early August, and mustard by late August, to develop sufficient biomass to provide soil protection, weed suppression, and other benefits; a delay of seven to ten days reduced biomass by half (Bjorkman et al., 2014).

Method and timing of cover crop termination can significantly affect outcome. For example; in Nebraska, legume-mustard mixtures planted in late March and terminated in late May with a sweep-plow undercutter (leaving residues on the surface) conserved moisture, reduced weeds, and improved yield of corn (17%) and soybean (23%). Terminating the same cover crops by disking accelerated soil moisture loss and reduced soybean yield 14% (Wortman et al., 2016). In New York and Michigan, leaving frost-killed residues of late summer planted buckwheat, sudangrass, or mustard on the soil surface over winter (rather than plowing them in

fall) reduced spring weed growth and improved vigor of a subsequent snap bean crop (Bjorkman et al., 2014).

Interseeding cover crops into standing production crops lengthens the growing season available to the cover crop and can enhance establishment and winter cover. For example, cereal rye and hairy vetch improved soil quality (total organic C and N, aggregation, P availability) and reduced weed pressure in Minnesota when successfully planted into standing corn, but post-harvest plantings did not develop sufficient biomass (Sheaffer et al., 2007). Promising results have been reported with perennial legume-grass cover crops frost seeded into grains in Pennsylvania (Barbercheck, 2016), and interseeded into corn or soybeans at the end of the critical weed-free period (5-leaf and 4-leaf stages, respectively) in upstate New York (Caldwell et al., 2016). In the latter example, a drill interseeder planted three rows at 7.5 inch spacing between corn or soybean rows on a 30 inch spacing.

A four-year rotation that included two years in alfalfa or red clover proved more practical and provided greater soil and weed (Canada thistle) suppression benefits than a two-year rotation with winter covers (Sheaffer et al., 2007). Corn-soy-alfalfa can be diversified by adding crops that can serve either as covers or livestock feed, including buckwheat, millets, flax, sunflower, and winter cereal grains; of these the sunflower and cereal grains performed best in trials in Minnesota (Sheaffer et al., 2011).

Because of its winter-hardiness (to -40°F), cereal rye is widely used in colder regions, and organic soybean generally performs well after rye covers. Soybean planted no-till into roll-crimped rye has given high yields in PA (Barbercheck, 2016; Barbercheck et al, 2014) and Missouri (Clark, 2016), and yield tradeoffs associated with reduced till systems further north have been less severe for soybean planted no-till into rye than for corn or cereal grains planted no-till into legume or mixed cover crops (Delate, 2013). In addition, rye cover crops tilled in before soybean have also reduced soybean aphid levels in multi-site trials in Minnesota (Heimpel et al., 2008), and organic soybean planted no-till into rolled rye + vetch had high yields and very little rust or other diseases in IA (DeWitt, 2008).

In vegetable production, one promising strategy is to alternate a year of intensive vegetable production with a full year in cover crops. Double cropping spring spinach or peas with fall brassicas has enhanced net economic returns in such rotations in New York, and the cover crop year helped keep weed populations down (Drinkwater et al., 2014).

Selecting and Managing Cover Crops for Warmer Climates: The Lower Midwest, Mid-Atlantic and Southern Regions

Regions with longer growing seasons and sufficient rainfall offer greater opportunities to grow cover crops to high biomass (6-8,000 lb/ac aboveground dry weight) within the same calendar year as the production crop. In addition to winter annual legume + cereal grain combinations (e.g., Cavigelli et al., 2014; Hooks et al., 2015; Morse et al., 2007), high biomass warm-season cover crops such as sunnhemp in Florida (Delate et al., 2015), AL (Kloepper et al., 2010) and HI (Chen et al., 2015), and sorghum-sudangrass, sunnhemp, and cowpea planted after winter wheat in Missouri (Reinbott et al., 2015) have been successfully integrated into crop rotations. Tropical (e.g., Virgin Islands) and subtropical (e.g., south Florida) regions that lack winter freezes pose special pest and weed management challenges for organic producers, but also allow a wider choice of cover crop species, including velvetbean, American jointvetch, and hairy indigo as well as cowpea, millets, and sorghum-sudangrass (Chase, 2016; Chase et al., 2010).

Winter cover crops readily attain high biomass in the southern region (Reberg-Horton, 2012), and rye “consistently performed the best” in Alabama, with greater biomass and weed suppression than other covers (Kloepper et al., 2010). Rye and hairy vetch produced sufficient biomass to suppress weeds when roll-crimped in Missouri, whereas crimson clover and Austrian winter pea did not (Reinbott et al., 2015). In Texas, a winter cover crop of crimson clover + wheat produced >4,000 lb/ac biomass and 78 lb/ac N when grown before rice in the crop rotation (Zhou, 2016).

Again, cover crop termination method can impact soil benefits. For example; in North Carolina, winter legumes terminated by flail mowing supported greater microbial biomass and release of PAN than disking or herbicide (Hu et al., 2015).

Cover Cropping Challenges and Opportunities in Semiarid Regions

Dryland grain production systems often entail a year of production, alternating with a year of fallow to accumulate and conserve moisture from limited rainfall. However, a bare fallow year can degrade soil quality and thereby reduce soil fertility and moisture capacity in the long run, whereas high biomass cover crops can enhance fertility and moisture storage in semiarid region soils (Archuleta, 2014). Yet, growing a cover crop in the fallow year can leave less moisture for the next production crop and thereby reduce yields.

Several research teams in the Great Plains and Intermountain West have experimented with cover crops, seeking strategies that might resolve this dilemma and support more sustainable dryland grain production.

Adding winter field pea as a cover crop to the rotation just before spring wheat has improved dryland wheat yields in eastern and central Washington, whereas *spring* plantings of field pea performed poorly because of weed competition (Gallagher et al., 2006). Winter pea has also been cited as the best green manure in Montana because of “comparatively efficient soil water use and significant nitrogen contribution to subsequent winter wheat” (Miller et al., 2009).

Either perennial or winter annual legumes during the three-year organic transition period in Washington improved soil fertility, weed control, and subsequent organic dryland grain yields (Borrelli et al., 2011). Overseeding “compatible” types of clover into wheat has also shown promise (Burke et al., 2014). On the other hand, high biomass, multispecies, warm-season cover crops grown during the year prior to grain corn in Nebraska resulted in a 5-10 bu/ac yield loss, which was related to a 1.5-inch reduction in springtime available soil moisture for the corn (Thompson et al., 2016).

Cover Crop Genetics

Cover crop genetics may play a significant role in performance in organic systems and/or in specific regions. For example, in trials conducted at two MN sites, hairy vetch land races sourced from farms within MN had far better winter survival (42-58%) than seed obtained from Michigan, Illinois, Missouri, or Ohio (2-12%); thus “seeds of hairy vetch cover crops should be produced in the region of intended use” (Moncada and Sheaffer, 2010). Similarly, fava bean strains vary widely in cold tolerance, and four lines that are winter-hardy in southeastern Washington (Zone 6b / 7a, about 0 F) have recently been registered (Landry, 2017). Different lines of hairy vetch can also vary in flowering date and ease of termination by roll-crimper (Farris, et al., 2017).

In 2015, an OREI-funded research team initiated a plant breeding endeavor to develop regionally adapted, improved lines of hairy vetch, crimson clover, and Austrian winter pea, with field trials in Maryland, North Carolina, New York, and Washington (Mirsky, 2015). Breeding objectives will be informed by participant farmers, and will likely include fall establishment, winter survival, spring flowering date, biomass, N fixation, and ease of termination by non-tillage mechanical means.

Questions for Further Research in Cover Crops and Soil Health for Organic Systems

Practical, research-based cover crop information is most available for field crop producers in the North Central region, for whom the Midwest Cover Crop Council (MCCC) has established a detailed decision tool for corn-soy-cereal grain producers in nine states and one Canadian province (Ontario). MCCC offers a similar tool for vegetable growers in Michigan only. Further work is needed to generate farmer-ready cover crop information and decision support for other regions and for horticultural crop, diversified, and crop-livestock integrated farming systems.

Initiatives to address some of these needs include a Northeast Cover Crop Council, recently established through a NE-SARE PDP project (awarded in 2016) with goals similar to MCCC; and a Southern Cover Crop Council, first proposed in an informal meeting at the July 2016 Southern SARE cover crop conference and currently in the planning stage.

Other research priorities include:

- A substantial long term investment in cover crop plant breeding and public cultivar development for organic and sustainable producers in all major US agro-ecoregions.
- Cover cropping strategies for dryland organic production in semiarid regions, including moisture-efficient cover crop species or varieties for semiarid regions.
- Additional research on the soil health benefits of various cover crop mixes from grass-legume bicultures to highly diverse cocktails, leading to practical guidelines for optimizing long term soil health and fertility outcomes.
- Further elucidation of inter-specific competition and complementarity dynamics in cover crop cocktails, leading to practical guidelines to help farmers design the best mixes for their climates, soils, production systems, and cover cropping objectives.
- Additional research into plant-microbe dynamics and nutrient cycling leading to practical guidelines to help farmers optimize soil health and fertility outcomes with cover crops.
- Further elucidation of “rotation effects” and specific effects of cover crop species on subsequent production crop species.
- The impacts of cover crop management practices, especially timing and methods of termination, on soil health and fertility benefits.

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Notes



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