Cover Cropping for Soil Health and Fertility in Organic Production

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Presentation Notes

Slide 2 – *Why cover crop?*
Slide 3 – *Sustenance for soil life*

A healthy, living soil is the foundation of all successful farming. Living plants sustain soil life through their continuous provision of root exudates as well as seasonal deposition of plant residues. Without the "plan B" of fast-acting soluble fertilizers and synthetic pesticides and fungicides, organic farmers especially depend on the soil life for day-to-day crop nutrition and resilience to disease and other stresses.

In a typical Midwest corn-soy rotation without cover crops, the soil remains fallow for eight months of the year, which increases erosion risks and cuts off the supply of living roots and their nourishing exudates – and the soil life goes hungry, goes dormant, and may partially die out, resulting in a reduction in functional soil biodiversity for the next season's crop. Planting a winter cover crop immediately after harvest provides a "green bridge" that sustains arbuscular mycorrhizal fungi (AMF, for which legumes, cereal grains, and most other grasses are excellent hosts) and other beneficial rhizosphere (root zone) micro-organisms.

Slide 4 – *Purposes of Conservation Practice Standard Cover Crop (Code 340)*

Slide 5 – *Cover crops and the five principles of soil health*

A vigorous, high-biomass cover crop "armors" the soil while growing and after any kind of termination that does not entail tillage, and maintains living roots during its growing period. Adding cover crops to the rotation generally increase diversity, and does so most effectively when cover crops are unrelated to the preceding or following production crop, when diverse mixes from multiple plant families are used, or when successive cover crops are chosen from different plant families.

Multiple studies have shown significant benefits of adding just one or two new cover crops or production crops to an existing low-diversity rotation such as corn-soybean (McDaniel et al., 2014; Moncada and Sheaffer, 2010). Soil mycorrhizal populations may double after cover crops such as oats, rye, sorghum, sunnhemp, bahiagrass, and other legumes and grasses (Douds, 2015; Duncan, 2017; Finney et al., 2017).

Although cover crop termination without herbicides may require entail tillage, the use of cover crops reduces soil disturbance in other ways. First and most important, prompt cover crop planting avoids the severe disturbance of soil microbiome starvation during prolonged periods without vegetative cover or living roots. Second, using cover crops can reduce the need for inputs (fertilizer, pest and weed control materials), and the need for repeated cultivation to manage weeds.

Integrating livestock into cropping systems, now widely considered the fifth principle of soil health management, can be facilitated by cover crops, many of which make excellent forage. CPS 340 Cover Crop allows cover crop grazing provided that the grazing is managed to ensure that conservation objectives are not compromised.

Slide 6- *Cover crops in the National Organic Standards*
Slide 7 – *Cover crops: a multi-purpose tool for organic farming.*

The National Organic Standards require certified organic farmers to protect and enhance soil, water, and other resources, and to use cover crops as part of the farm's nutrient management system. The organic standards also require a crop rotation including cover crops to prevent erosion, build soil organic matter (SOM), and to help manage deficient or excess nutrients.

The combined action of cover crop roots and the soil microbiome relieves near-surface and subsurface compaction, builds and maintains soil aggregation and porosity, and thereby enhances the soils' capacity to hold plant-available moisture and facilitates deep, extensive root growth that further improves crop access to nutrients and moisture.

As a vital source of organic carbon to feed soil life and maintain soil organic matter, high biomass cover crops enhance the soil's long-term capacity to provide for crop nutrition. Winter grass and legume cover crops sustain mycorrhizal populations for the next crop.

Cover crops help to regulate soil nutrient levels. When soil soluble N is scarce, legumes maximize N fixation, and some warm season grasses host N-fixing bacteria in their root zone. When soil soluble N is abundant, these cover crops switch to "scavenging mode," absorbing and holding the surplus N, thus protecting water quality and providing for future crop nutrient needs.

When plant-available P or K are below optimum, cover crops enhance their availability. Buckwheat and some legumes and grasses can retrieve P from insoluble organic and mineral sources (including rock phosphate amendments), while most grasses can unlock "mineral-fixed" K to replenish the supply of exchangeable (plant-available) K. However, cover crops do not contribute to P and K excesses when soil levels are already ample.

Cover crops suppress weeds by occupying the ground while fields are not in production. They also disrupt the life cycles of certain pests and pathogens, and flowering cover crops provide habitat for pollinators and natural enemies (predators and parasitoids) of crop pests. While cover crops alone cannot solve a weed, pest, or disease problem, they often comprise a major component of an organic farm's IPM strategy.

Slide 8 – *Percentages of farmers who plant cover crops*

Organic farming systems rely to a great degree on cover crops for multiple functions, especially crop nutrition and crop protecition for which they cannot resort to synthetic agrochemicals when nutrient or pest problems arise. Thus, most organic producers use cover crops regularly.

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

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

Slide 9 – *Cover cropping challenges and strategies: selecting cover crops.*

Slide 10 – *Selecting cover crops to stop erosion and crusting*

The photo was taken 53 days after alternate rows of southern pea and foxtail millet were sown immediately after harvest of spring vegetables at Charlie and Miriam Maloney's Dayspring Farm in the Tidewater region of Virginia.

Slide 11 – *Cover crops save soil in community garden in Floyd, VA.*

This demonstration of the value of cover crops took place in the co-presenter's home community. His farmer neighbor, Abel Duffy, planted a sorghum-sudangrass cover crop the day after potato harvest in July. The cover crop was flattened by the September 29 flood and its heavy top growth and robust root mass protected the soil so that not one shovelful was lost to the river. The sorghum-sudangrass bounced back within a week and resumed growth until first frost.

Slide 12 – *Selecting cover crops to build SOM, feed soil life the engine of soil fertility*

The fundamental purpose of cover crops is to fuel and sustain the community of soil life during the "off season between successive production crops, and in orchard floors and alleys in vineyards and other perennial crops. The soil microbiome and its larger and macroscopic predators drive soil fertility and crop nutrition. A balanced, diverse, well-fed soil biota carries out all key functions of a healthy soil: build and maintain active and stable SOM, provide for crop nutrition while holding nutrients against leaching, protect crops against pathogens, and maintain an open and porous soil structure that absorbs and holds moisture, maintains aeration, and supports deep, extensive root development.

High biomass cover crops with persistent residues – primarily cereal grains and other grasses – have often been recommended for building SOM and soil health. However, soil life needs *both* organic carbon and organic nitrogen to thrive, grow, and transform organic residues into stable SOM. Studies have shown that organic inputs with a balance of carbon and nitrogen (C:N ratio ~25–30:1) build SOM more effectively than inputs with very low (chicken litter) or very high (corn stover) C:N ratio (Bhowmik et al., 2017; Fortuna et al., 2014; Grandy and Kallenbach, 2015). The same may be true for cover crops; it is known that succulent, low C:N green manures stimulate microbial activity and enhance active SOM, but do not accrue much stable SOM. Combining cover crops with organic amendments such as finished compost can further enhance soil health outcomes (Hurisso et al., 2016).

Plant biomass and biodiversity support abundant, diverse soil life, and can be accomplished either through complex mixes or cocktails, or by using different one- or two-species cover crops throughout the rotation.

Cereal grains, most other grasses, and most legumes are strong mycorrhizal hosts. Buckwheat and crucifers (radish, mustard) are non-hosts and a cover crop dominated by crucifers may temporarily depress soil mycorrhizal activity.

Perennial grasses and legumes maintain much higher root biomass than annuals, and a perennial sod or "prairie mix" is most effective for restoring the health of a depleted soil, such as during the three-year organic transition period (Borrelli et al., 2011; Briar et al., 2011).

Slide 13 – *Selecting cover crops to improve topsoil structure*

Dense, fibrous root systems, such as those of ryegrass and cereal grains, provide a rich supply of root exudates to support the growth of soil microbes, which in turn promote soil aggregation and improve tilth. Including a legume (if soil soluble N is low to moderate) or a succulent broadleaf such as buckwheat or radish (if soil soluble N is ample) to provide a more balanced C:N ratio for the soil microbiome may further enhance biologically driven soil aggregation.

Slide 14 – *Selecting cover crops to relieve hardpan and retrieve subsoil nutrients*

Cover crops such as pearl millet, sorghum-sudangrass, sunflower, sunnhemp, radish, and winter rye penetrate subsurface hardpan, leaving pores and channels that facilitate deep rooting by subsequent production crops (Marshall et al., 2016; Rosolem et al., 2017). Pearl millet can penetrate naturally compacted and acidic subsurface soil layers that stop the root growth of most other crops, effectively scavenging nitrate-N from within and below the compaction layer to a depth of six feet (Menezes et al., 1997). Tillage radish scavenges large amounts of nitrogen (N), phosphorus (P), and potassium (K), and leaves deep macropores that enhance rooting depth and nutrient uptake of the following corn crop (Gruver et al., 2016).

Deep rooted grasses can unlock K from subsoil minerals, thereby providing an important source of this nutrient on "low fertility" soils such as the Ultisols of the southeastern US coastal plain (Kloot, 2018). The presence of living roots and their associated microbiomes deep in the soil profile can also help solubilize and retrieve essential micronutrients, sequester carbon well below the tillage depth, and improve subsoil porosity, drainage, and water holding capacity.

Pearl millet and sorghum-sudangrass in particular can protect water quality and curb nitrous oxide (N_2O) emissions by aggressively scavenging nitrate-N from the soil and by releasing natural nitrification inhibitors (Rosolem et al., 2017).

Slide 15 – *Selecting cover crops to provide and manage nutrients*

Grass and legume cover crops show complementary nutrient dynamics. Most farmers know from experience that a single species cover crop of cereal grain or sorghum-sudangrass can tie up N and increase crop requirements for applied N; while a legume cover crop can reduce or even eliminate the need to add N for optimum yields.

Researchers have documented substantial leaching of nitrate-N and N_2O emissions after tilling-in an all-legume cover crop such as hairy vetch or red clover (Grossman, 2012; Han et al., 2017; Heilig and Hill, 2014; Teasdale, 2012). A recent meta-analysis and modeling study covering 8,000 sites across Europe indicated that regular use of all-legume cover crops can result in N_2O emissions that negate the climate-mitigation benefits of carbon sequestration by the cover crop (Lugato et al., 2018). Combining a legume with a cereal grain or other grass provides slow-release N with less leaching and N_2O emissions (Baas et al., 2015; Teasdale, 2012) and the grass can enhance total N fixation per acre by consuming soluble N from the soil and providing physical support for viny legumes like vetch or field pea (Andrews and Sullivan, 2010; Drinkwater, 2011).

Slide 16 – *Selecting cover crops to suppress weeds*

The southern pea in this photo was grown in a summer cover crop trial that was planted in a weedy seedbed; it was the only cover crop that did not become weedy by the time this photo was taken.

In another trial, a winter cover crop of rye + vetch remained nearly weed free for eight weeks after no-till termination by mowing, while rye alone became infested with horseweed (which tolerates low soil fertility), and vetch alone with pigweed (which responds to high soluble N levels).

Organic integrated weed management including the use of cover crops was covered in greater depth in the Weed Management webinar in this series (March 20, 2023).

Slide 17 – *Selecting cover crops to deter pests and pathogens.*

Some pests and diseases can be managed by lengthening and diversifying the crop rotation and adding strategically selected cover crops.

Choose cover crop species that are not closely related to the immediately preceding or following production crops – from a different plant family as a rule, though winter cereal grains can often follow corn or sorghum, and cool- and warm-season legumes from different sub-families can often follow each other. On the other hand, some pests can affect unrelated plant families, for example, root-knot nematode can proliferate on some clovers and seriously affect subsequent vegetable crops from several plant families.

Southern pea, sunnhemp, and sorghum-sudangrass have been recommended for reducing populations of plant root feeding (pest) nematodes, but their efficacy varies with cover crop cultivar and nematode species.

The crop rotation manual, jointly published by SARE and the Natural Resources, Agriculture, and Engineering Service (NRAES) is based on input from a dozen experienced organic producers in the northeastern US, combined with research findings regarding impacts of different cover crops on a range of crop pests, including insects, weeds, plant root-feeding nematodes, and microbial pathogens. The manual provides extensive tables that help users identify the best cover crops to avoid or manage specific pest problems.

Slide 18 – *Selecting cover crops for biological pest control*

The adult phases of many pest predators and parasitoids, such as micro-wasps, hover flies, and lady beetles, depend on pollen and nectar for nourishment. Many cover crops provide these resources while flowering, and a few, including southern pea, have extra-floral nectaries on the base of their leaf petioles that support beneficials before the crop flowers.

Low-growing cover crops such as white clover or alyssum, and surface residues of mowed, roll-crimped, or winterkilled cover crops provide habitat for many generalist predators including ground beetles, spiders, and minute pirate bugs.

Cereal grains host aphid species that do not attack broadleaf plants. Leaving strips of grain standing close to vegetable or other broadleaf production crops can encourage lady beetles and other predators to remain within the field or farm ecosystem when the target pest is absent or scarce, so that the biological control services of the predators is available to limit future pest outbreaks.

Slides 19-20 – *Selecting cover crops for different rotation niches*

Some suggested cover crop species for different niches (unplanted time intervals) in the rotation. This is not an exhaustive list – other crops may be more suitable for your locale.

Slide 21 – *Cover crops for challenging soils and climates*

Soils with existing health challenges or inherent limitations may require special considerations in selecting cover crops – and cover crops that can successfully establish under these conditions will also help ameliorate limitations and restore soil health.

In addition to the examples listed here, including legumes in the mix will help address low or spatially variable levels of plant-available N in the soil. Where N is low, the legume will tend to dominate and enhance N levels; where N is ample or excessive, the non-legumes will dominate, mop up the surplus, and slow-release it to future crops.

As noted earlier, deep rooted cover crops (radish, pearl millet, sorghum-sudangrass, sweetclover) can penetrate subsurface compaction, and thereby markedly improve soil productivity.

Slide 22 – *Cover cropping challenges and strategies: establishment, nutrients, termination*

Slide 23 – *Tips for timely cover crop establishment*

Plant the cover crop *immediately* after harvesting the preceding production crop if at all possible. Better yet, eliminate the bare soil period between harvest and planting by interseeding or overseeding the cover crop into the cash crop before harvest. For example, clovers or southern pea into corn at the six-leaf stage, winter annual covers into maturing soybean just before its leaves fall (the leaves cover the seed and help keep it moist during emergence), or cover crops seeded into standing vegetable crops at last cultivation.

High quality seed is essential! There is nothing more disheartening for the conservation-minded farmer than a cover crop failure caused by old or weak seed.

Cover crops are not as fussy about fine seedbed and ample nutrients as most production crops. However, it pays to attend to basics to ensure prompt establishment of a good stand and vigorous growth. Poor seed-soil contact, old or low-vigor seed, and delayed planting of fall and winter cover crops are common causes of poor or weedy stands and reduced biomass.

When restoring nutrient-depleted fields or converting fields from conventional to organic production, applying compost or manure before cover crop planting can enhance biomass and soil health outcomes. *Exception*: if soil test P is above optimum, do not use manure (fresh or composted) to restore soil health. Include legumes tolerant to low fertility (e.g. sunn hemp, southern pea, hairy vetch) and address severe deficiencies in K, magnesium (Mg) or micronutrients with the appropriate NOP-allowed mineral nutrient sources.

If soil pH is excessively acidic or alkaline, select cover crops adapted to these conditions and amend soil (lime or sulfur) to adjust the pH.

When combining two or more species, each species can be sown at lower than its recommended rates for single-species stands. Reduce rates most for the most competitive species (e.g. in an oats-crimson clover mix, sow oats at 40-50% and clover at 75% of their respective full rates). Start by dividing sole seeding rates by the number of species in the mix, then observe results to adjust rates in future years.

Increase rates somewhat for weedy field and late plantings – however note that very high seeding rates (e.g., each species of a four-way mix at 100% of its sole-species rate) can be counterproductive, as overcrowding reduces vigor and biomass. It is also more expensive!

If soil and weather are dry, irrigate at time of planting if practical to get the stand established.

Slides 24-25 – *Examples of cover crop planting techniques – shallow tillage and no-till*

The farm in Slide 24 is located near West Point, VA in the Tidewater region, on a loamy sand Ultisol with considerable weed pressure. The excellent cover crop stand shown here will virtually stop winter weed emergence until the cover crop is terminated for organic vegetable production the following spring.

The farm in Slide 25 is located in Penn Yan in the Finger Lakes region of upstate New York. Klaas Martens grows 1,900 acres of organic grains, operates an organic grain marketing cooperative, and has participated with Cornell University for many years in highly innovative on-farm research into organic minimum-till grain and forage rotations. In this example, no-till drilling the rye and peas into sorghum-sudan stubble (after a forage harvest) yields sufficient cover crop biomass and stand uniformity for roll-crimping, thus facilitating a three-crop sequence of forage → cover crop → corn or soybean without tillage.

Slide 26 – *Organic farmer's cover crop termination dilemma*

Traditionally, legume cover crops grown to enhance soil fertility were incorporated into the soil as a "green manure" by deep, inversion tillage with a moldboard plow or disk plow. This level of soil disturbance undoes some of the soil health benefits of the cover crop, and yearly plowing can create a "plow pan" that restricts deeper root growth and thereby limits crop access to moisture and nutrients. Plowing an all-legume cover crop can also lead to N leaching and N_2O emissions (Han et al., 2017; Lugato et al., 2018). Spading machines, including reciprocal or rotary designs, can incorporate a high biomass cover crop (mowed first) in one pass without fully inverting the soil profile or creating a subsurface hardpan, but soil disturbance is still substantial.

Terminating the cover crop with a roller-crimper followed by no-till planting maximizes soil health outcomes but can entail yield tradeoffs related to N limitation and weed pressure. A well-designed roller crimper can do the job without either physical or chemical soil disturbance, but its success depends on a field history of excellent soil and weed management, a uniform, high-biomass, weed-free cover crop, and skillful adjustment and use of the tools. Even when all these factors are in place, cooler soil and slower N mineralization in untilled soil under a heavy cover crop residue can interfere with crop establishment or lead to crop N deficiency. Organic no-till and minimum till methods can be especially challenging to implement and manage successfully in northern regions with shorter growing seasons.

Slide 27 – *Cover crop termination options for organic systems*

Many organic producers manage cover crops by flail mowing followed by shallow, non-inversion tillage to mix residues into the top few inches of soil and prepare a seedbed. Although a rototiller operated at high rotary speed can pulverize near-surface aggregates and promote sealing, this damage can be substantially reduced by operating the tiller at lower rotary speed or by using a high-speed disk, rotary harrow, or vertical tillage implement to accomplish lower-impact shallow tillage. A recent meta-analysis has shown that "reduced tillage," defined as shallow (<6 inches), non-inversion tillage, can maintain twice the microbial biomass as either moldboard plowing or continuous no-till with chemical weed control and inadequate cover cropping (Morugán-Coronado et al., 2022).

Strip tillage prepares crop rows for planting while leaving 70-80% of the soil surface undisturbed and covered by residues. Strip tillage implements consist of a coulter to part residues followed by a shank or chisel to loosen soil to about 6 inches depth, and a narrow rolling basket (as shown in the slide), wavy coulter, or other tool to smooth the surface.

Tarping, sometimes called "occultation," is another no-till no-herbicide cover crop termination option that small scale organic market gardeners (up to a few acres) have found practical and effective. After the cover crop is mowed or roller-crimped, it is covered with opaque landscape fabric or silage tarp for several weeks to complete termination and kill emerging weeds through light deprivation. This system can delay weed emergence by several weeks after tarps are removed and the production crop is planted, and may provide better nitrogen mineralization than other organic no-till cover crop termination methods, thereby sustaining higher yields.

In the slide, Georgia organic vegetable and strawberry farmer Bryan Hager replaces the pre-plant tarp with landscape fabric with planting holes at the desired spacing for the crop to be planted, thereby effecting season-long no-till weed control.

Slide 28 – *Cover crop termination by winterkill*

Crop rotations can be designed to include cover crop termination by winterkill. Planting a non-winter-hardy cover crop early enough in the fall to generate substantial biomass before the first killing freeze can be a good strategy ahead of an early spring cash crop. Leaving frost-killed cover crop residues on the surface until shortly before planting protects the soil, allows ground beetles and other weed seed consumers to reduce weed seed populations, and can improve subsequent crop yields compared to fall tillage (Bjorkman et al., 2015). The weathered residues may require only light, shallow tillage to remove emerging weeds and prepare the seedbed.

Slide 29 – *Termination timing: a soil health / yield tradeoff?*
Slide 30 – *Mature cover crops build soil capacity to provide N*

The first question asked about cover crops and nitrogen dynamics is often: *how much N will the cover crop give to the subsequent production crop?* The answer for *direct* N transfer from decomposing cover crop residues to the next cash crop is higher for young, succulent cover crops than for more mature, high biomass cover crops. However, the mature cover crop provides far more organic C and N to the soil life, thereby contributing to the soil's capacity to mineralize N for crop nutrition in future years. In the early years of organic transition or restoring a depleted soil, crops planted after a mature, high biomass cover crop will need supplemental N to sustain vigor and yield. Organic producers can provide this N with poultry litter, guano, feather meal, blood meal, or seed meals. As best organic practices (including optimally mature, high biomass cover crops) build active SOM, soil organic N reserves, and soil biological activity, the soil provides more and more N via mineralization, and the need for applied N diminishes, sometimes to zero (Franzluebbers, 2018; Franzluebbers et al., 2018). For more information on organic nutrient management, see the archived NRCS webinar *Biological Nutrient Management: Best Organic Practices for Soil Fertility and Resource Stewardship* (February 6, 2023).

Slide 31 – *Cover crop maturity and N dynamics*

Cover crop photosynthesis, biomass accumulation, root exudation, and (for legumes) nitrogen fixation reach their highest rates during the crop's period of rapid growth and development – mid-vegetative stage through full bloom. After this time, photosynthesis, root exudation, and N fixation rates diminish, and the crop moves organic carbon, nitrogen, and other nutrients from vegetative tissues into the developing seeds. Thus, terminating cover crops at mid to late bloom and before seeds begin to mature or foliage begin to turn yellow or dry up gives the best results in term of soil biological activity, active and total SOM accrual, and overall soil health.

As a cover crop grows and matures, biomass and total N accrue slowly at first, and then exponentially during later vegetative growth and flowering. Young, succulent cover crops are N rich (low C:N ratio), and thus release N rapidly if terminated at this stage. Crop C:N increases through the phases of rapid biomass accrual, flowering, and seed development and maturation.

The green line in the graph shows the amount of cover crop N that is mineralized and taken up by the following production crop, based on isotope tracer studies. Note that as the cover crop matures and that line goes to zero or below (net immobilization) the nitrogen is not lost; it is stored in active SOM, from which it can be released to future crops.

When grown to their full height and full-late bloom, cover crops make their greatest *total* contributions to SOM, organic N, and microbial growth Terminating the cover crop just four weeks earlier (late vegetative) can reduce biomass and organic matter contributions by half.

An all-grass cover crop terminated after pollen shed, or any cover crop allowed to mature until leaves turn brown and dry, will tie up soil N and increase the need for N inputs, especially if cover crops are tilled in. High C:N residues are less nourishing to soil life and build less active and stable SOM than residues with moderate C:N (~20 – 30:1) (Grandy and Kallenbach, 2015).

Research at Cornell into organic reduced till / cover crop systems has shown that cabbage yields are inversely related to cover crop C:N ratio, with vetch alone or zone planted vetch/rye (C:N 12 – 30) giving the highest yields, and other treatments with cover crop C:N 40 -80 requiring 60 to 120 lb additional N per acre to attain the same yields (Cornell, 2018).

Slide 32 – *Cover crop types and N dynamics*

An all-legume green manure (cover crop plowed down), especially a perennial like red clover or alfalfa, can meet all of the N requirement of a following organic crop of corn or other heavy feeder. A succulent crucifer crop like radish can also release N rapidly after termination by tillage. However, N_2O emissions and N leaching losses can be substantial (Han et al., 2017).

A grass-legume bicullture or multispecies mix of these two with other plant families (crucifer, buckwheat, sunflower) can provide the “sweet spot” for organic nutrient management. In addition, N fixation potential is maximal in high-biomass mixes in which legumes comprise about 50% of aboveground growth. N demand by the non-legumes stimulates increases legume N fixation. In addition, mixes are most responsive to varying soil conditions, maximizing N fixation where existing soil soluble N levels are low, and maximizing N scavenging where soil N is abundant – in effect, a biological approach to precision farming.

Some grasses, including millets and indigenous land races of corn, support N fixing microbes in their root zones that can contribute 10 – 50 lb N/ac when existing soluble N levels are low. Deep rooted grasses (pearl millet, sorghum-sudangrass, perennials), crucifers (radish, canola), and some other forbs (such as chicory) can recover soil nitrate-N to depths up to 5-8 feet.

Slide 33 – *Can this cover crop mix meet the N needs of the next crop?*

Some organic producers aim to meet most or all of their crop nutrient needs from cover crops and on-farm generated residues.

The cover crop mix in the slide includes pearl millet, sorghum-sudangrass, southern pea, sunflower, and buckwheat. It was sown in early summer, cut back six weeks after emergence and allowed to regrow to enhance root growth while maintaining a moderate C:N ratio. Can this cover crop meet the N needs of the following crop? The answer depends on a range of factors.

In a review of 130 published papers on organic grain cropping systems that utilized cover crops and animal manure as nutrient sources, Carr et al. 2020) found that:

- Cover crop-supplied N can meet organic crop needs in warm, humid regions (southeastern US) but not in cool (Northeast, upper Midwest, Canada) or dry (Great Plains, Intermountain West) regions.
- Adoption of organic no-till systems can result in N deficiencies in grain crops.
- Use of animal manure to supplement soil fertility can lead to soil N and P excesses.

Multiple trials have shown improved soil health but reduced yields in field crops planted no-till into roll-crimped cover crops, especially in northern regions. Yield losses were attributed to N limitation and weeds. Corn and oats were more severely affected (63% yield loss) than soybean (31% loss). In the mid-Atlantic (PA, MD, DE) and lower Midwest (MO), the N-fixing soybean gave full yields when planted no-till into roll-crimped rye, while corn still showed some yield reductions, clearly illustrating the role of delayed N mineralization in the soil health / yield tradeoff (Barbercheck, 2016, Barbercheck et al., 2014, Clark, 2019, Delate, 2013).

In the Pacific Northwest, no-till organic squash or brassicas did very well in sandy soils and poorly in silt-loams (Smallwood et al., 2015).

Slide 34 – *N tie-up can favor N-fixing crops over weeds*

An all-rye cover crop takes up soluble N from the soil and its residues are slow to release it after roller-crimping. The resulting low levels of plant-available N slows emergence, establishment, and growth of "N-responder" weeds like lambsquarters, pigweeds, ragweed, and foxtails, while soybean, a strong N fixer, is little affected by the N deficiency. The outcome is selective weed control by the rye mulch for soybean. A high soybean seeding rate helps to ensure a good stand and high yield (Menalled et al., 2021). The rye mulch has also been found to inhibit white mold, one of the most severe diseases of soybean, dry bean, and other pulses (Pethybridge and Ryan, 2021). Initial experiments with no-till organic dry bean in roll-crimped rye have given promising results. The researchers will also try this method with oilseed sunflower crops.

Slide 35 – *Regional cover cropping challenges and strategies*

Slide 36 – *Northeast and North Central regions. Leading challenge: short growing season*

In colder regions with limited growing seasons and severe winters, it is difficult to fit cash and cover crops into the rotation – and growers are often faced with a tradeoff between terminating cover crops early (greatly reducing organic matter and other benefits) or shortening the available growing period for the cash crop, resulting in lower yields.

While roll-crimping or mowing the cover crop may save some time, yield tradeoffs with no-till cover crop management are often most severe in cooler regions because of stand establishment challenges with cover crop residues and slower soil warming.

Cover crops can be interseeded into standing corn, soybean, and other row crops. Rye + vetch planted into standing corn improved soil quality in Minnesota (very short growing season), while post-harvest cover crop plantings did not develop sufficient biomass to confer benefits (Sheaffer et al., 2007). In upstate New York, cover crops were successfully established at last cultivation, which occurred at the 4-leaf stage in soybean or 5 leaf stage in corn (Caldwell et al., 2016). Cash crops were planted in rows 30 inches apart, and a drill interseeder was used to plant three rows of cover crop (7.5 inch spacing) in each alley.

Slide 37 – *Making the best of a short growing season*

These are some creative ways in which vegetable growers in the Northeast region meet the growing season challenge through relay cropping. Sweet corn/soybean and tomato/clover examples are from Eliot Coleman's market garden in central Vermont (Coleman, 1989). The potato example, an experiment conducted by Dr. Ron Morse of Virginia Tech in the Appalachian region of Virginia (zone 6b-7a) gave substantially greater cover crop biomass as well as a potato yield increase of about 17% compared to tilling the cover crop in before planting.

Resources:

- **Northeast Cover Crop Council** http://northeastcovercrops.com/.
- **Midwest Cover Crop Council** https://www.midwestcovercrops.org/.

Slide 38: *Interior western region. Leading challenge: limited water*

In semiarid regions, cash crops and cover crops in the rotation can vie with one another- and with weeds – for limited moisture. As a result, it is more difficult to grow a cover crop to sufficient biomass to provide substantial benefits in terms of erosion control, organic matter, N fixation, weed suppression, and grain yields. If the cover crop does attain high biomass, it may also consume so much moisture that grain yields become severely water-limited. Terminating the cover crop by tillage can further compromise benefits, as semiarid regions soils are especially prone to wind erosion, SOM loss, and reduced fertility. No-till termination is often complicated by perennial weeds. Yet, not growing a cover crop can further reduce SOM and fertility, aggravate erosion, and reduce long term soil water holding capacity (Lehnhoff et al., 2017).

In the Northern Great Plains, long cold winters and short growing seasons further limit options for cover crop-based rotational no-till. Climate change is intensifying the challenges with warmer, drier springs and more intense summer drought and heat.

Slide 39 – *Cover crops for semiarid climates*

Foxtail and pearl millets, southern pea, berseem clover, and barley combine drought resilience with low water demand, and are thus good candidates as cover crops for low-rainfall regions. While not quite as drought tolerant, a winter cover crop of field peas has shown promise for building soil health and providing N to subsequent crops without depleting soil moisture in the northern Great Plains and interior Pacific Northwest (Gallagher et al., 2006; Miller et al., 2009).

Resources:

- **Western Cover Crop Council** https://westerncovercrops.org/.
- **USDA Cover Crop Chart** https://www.ars.usda.gov/plains-area/mandan-nd/ngprl/docs/cover-crop-chart/.

Slide 40 – *Coastal Pacific Northwest. Leading challenge: dry summer, rainy winter*
Slide 41 – *Interplanting cover crops into organic vegetables*

Timely and effective cover cropping can be especially difficult in a climate where it rains all winter and shines all summer, such as northern California or the maritime Pacific Northwest. Many cool season cover crops – bell bean, winter pea, crimson clover, cereal grains – are well adapted to the region's winter conditions, but their use is hindered by late harvest dates of many warm season vegetable crops, and difficulties getting into the field to plant if heavy winter rains set in before harvest is complete. Nick Andrews and colleagues at Oregon State U are using a drill designed for interplanting cover crops into standing cash crops (Andrews, 2014, 2016). A wide range of cover crops, including cereal grains, sorghum-sudangrass, crimson clover, vetches, and some perennials like orchardgrass, fescue, and red clover, have been planted into production crops at midgrowth, for example, sweet corn at the six-leaf stage, just before last cultivation.
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Slide 42 – *Southern region. Leading challenge: summer heat*

In the hotter parts of the South, many vegetable growers take fields out of production during summer months, when high temperatures, dry spells, intense weed competition, and other pest problems complicate crop production. Some weeds such as Palmer amaranth and purple nutsedge attain their greatest growth rates near 100 degrees F, a temperature that severely limits growth, pollination and fruit or grain set in most food crops.

Leaving fields unplanted through the hot summer will burn up SOM and degrade soil health, while planting them in heat-loving crops like these tropical grasses and legumes will protect and restore the soil.

The region's long growing season and mild winters allows active cover crop growth 12 months of the year. Rye can *survive* a Vermont winter and can *make tons per acre biomass* in a Georgia winter. Throughout most of the South, farmers can integrate one high-biomass cover crop and one or more production crops in each calendar year of the crop rotation.

These photos were taken at North Carolina State University Center for Environmental Farming Systems (CEFS) at the 2016 Southern SARE Cover Cropping Conference, July 19 2016. Other heat loving cover crops include pearl millet, southern pea, velvet bean, and pigeon pea.

Slide 43 – *Southern region. Additional challenge: low-fertility soils*

In a coastal South Carolina study, a rye cover crop, facilitated by adequate soil moisture from winter rains, was able to penetrate the compacted E horizon, allowing the following cash crop (cotton) to send its roots deeper, obtain sufficient moisture, and give good yields (Marshall et al., 2016). Without the cover crop, cotton yielded poorly unless deep (subsoil) tillage was performed before planting. Two years of rye cover cropping also significantly enhanced SOM over the no-cover treatment on these sandy soils.

Sorghum-sudangrass, pearl millet (summer), tillage radish (fall), and sweetclover (biennial) are even more powerful subsoiling crops than rye.

Slide 44 – *Cover crops in context and farmer stories*

Slide 45 – *Cover crops in synergy with other soil health practices*

Multiple studies have shown that organic amendments, especially finished compost, can work in a complementary and synergistic manner with living plants (cover crops, tight diverse crop rotations, etc) to build SOM and soil health (Brennan & Acosta-Martinez, 2017; Delate et al., 2015a; Hooks et al., 2015; Hurisso et al., 2016). Vigorous cover crops enhance soil biological activity while compost adds stable SOM and may help stabilize the SOM deposited by crop roots. Relatively small amounts of compost that do not aggravate P surpluses may suffice to obtain these enhanced outcomes, and additional measures to reduce tillage intensity further enhance SOM accrual (Cavigelli et al., 2013; Delate et al., 2015a). Integrated systems of practices generally yield greater benefits than single practices such as compost without cover crops or vice versa.

Results of six long-term farming systems trials across the US show that organic crop rotations that include legume cover or sod crops, organic nutrient sources (compost or manure), and some routine tillage can outperform conventional corn-soybean rotations in SOC sequestration (Delate et al., 2015b). The perennial legume or legume-grass sod phase in the organic systems increases the depth, biomass, and duration / continuity of living roots, and thus play a major role in SOC accrual in these systems (Wander et al., 1994).

In the Beltsville, MD long term agroecological research (LTAR) trial, total soil organic carbon (SOC) measured from surface to 39 inch depth) at the end of 13 years were 5 tons/ac higher in organic rotations with cover crops, light applications of poultry litter (0.7 – 1.3 t/ac annually), and some tillage, than in a conventional no-till system, and 7.8 tons/ac higher than in a tilled conventional rotation (Cavigelli et al., 2013).

Slides 46-48 – *Adaptive cover cropping at Twin Oaks Farm, Louisa, VA*

Farmer, author, educator, and VABF member Pam Dawling has developed an ingenious and flexible approach to maximizing soil coverage, living root, plant biomass, and diversity through cover cropping in four-acre vegetable operation that stocks a community kitchen serving up to 100 people.

Pam has developed her ten-year crop rotation and detailed guidance for what cover crop to plant and when to plant it, based on personal experience and knowledge gained through decades of farming at this site. She has given many webinars and presentations on this topic. For more information on her cover cropping strategies, species selection, and scheduling, and on many other topics, visit her web site at www.sustainablemarketfarming.com.

Pam has tried various undersowing strategies with good track records in the Northeast and has found that not all of them work in Virginia. For example, she does not overseed rye and vetch into kale because the latter is harvested well into winter in central Virginia; red clover seeded into winter squash at onset of vining is choked out as the vines grow so rapidly in the heat of a Virginia Piedmont summer; and crimson clover is a poor choice for undersowing corn because it is just too hot for this cool season crop.

She notes that if the overseeded cover (such as soybean and oats into sweet corn, or clovers into fall brassicas) is sown too early, it may compete against the food cop, and if it is sown too late, shade and moisture competition from the food crop will prevent or hinder cover crop establishment. In addition, cultivating to remove weeds or work-in cover crop seed may damage the roots of large plants, such as corn more than knee-high. Thus, precise timing has been part of her success, both with relay planting and post-harvest cover crop planting.

Slides 49-51 – *Cover cropping for dryland organic grains at Vilicus Farms, Havre, MT*

In a cold-temperate region that receives on average 11.7 inches of rain per year, where the most common practice is one year in wheat alternating with a full year of unplanted fallow, Doug Crabtree and Anna Jones Crabtree of Vilicus Farms in Havre, MT have developed a highly diverse production system. They grow and market wheat, specialty grains, oilseeds, and pulses in a seven-year rotation that maintains vegetative cover and living roots each year and includes two years' green fallow with regionally-adapted cover crops.

Their rotation is structured for flexibility to respond to ever-changing weather conditions and market demand:

- **Year 1 Light feeding grain**: spelt, emmer, einkorn, barley or soft wheat with lower demands for nutrients and moisture, are planted April 15 – May 15. Grains are harvested in late July or August, leaving 4 – 8" stubble and straw spread across the field.

- **Year 2 Green fallow:** annual legume or cocktail mix planted late March or early April, *or* biennial sweet clover interseeded with the preceding grain crop. In June, beef manure + bedding is applied just before terminating the green fallow with shallow tillage.
- **Year 3 Heavy feeding grain**: hard red winter or spring wheat, or durum wheat, their highest-value crops, are planted after manure application to ensure sufficient nutrients.
- **Year 4 Broadleaf crop or oats:** safflower, flax, mustard, camelina, buckwheat, or oats are planted in April - May and harvested in September. Oats are included in this block because "they have a beneficial effect on the soil ecosystem, very different from other cereals."
- **Year 5 Pulse crop:** pea, lentil, or chickling vetch for seed, sown in April – May and harvested in August.
- **Year 6 Oats, broadleaf, or light-feeding grain:** A crop not grown in the field earlier in the rotation cycle is planted in spring and harvested in August or September.
- **Year 7 Green Fallow:** sweet clover interseeded into the Year 6 crop (if annual covers in Year 2), *or* annual legumes or mix (if sweet clover in Year 2), terminated in June.

With climate change making rainfall patterns increasingly erratic (with some years recording as little as 3 inches total, others over 20 inches), the farmers must take a highly adaptive approach. For example, they prefer to use a blade plow (sweep plow undercutter) to terminate cover crops and manage weeds, as it leaves 90% residue cover. However, this tool requires just the right soil moisture conditions to work properly, and plan B for too dry or too wet conditions is the speed disk, which leaves 50-60% residue cover. Cover crops are terminated in June or early July to avoid depleting soil moisture and thereby hurting the following grain crop.

In recent years, the farm has added a beef enterprise, terminating some of the green fallow acres by grazing, which also adds manure for fertility, and thus reduces reliance on off-farm manure for the heavy feeding modern wheats (Year 3 in the rotation).

The diverse rotation and cover cropping have improved SOM and soil health, thereby building resilience to the weather extremes.

Slides 52-53 – *Cover crops save and improve soil at Burnt Rock Farm, Huntington, VT*

This farm story is based on a presentation by farmer Justin Rich at the Northeast Organic Farming Association, Vermont Chapter conference held in February, 2022.

"Vegetables are hard on the soil, and potatoes are especially tillage-intensive," Justin noted. When he explored no-till weed control options, he found that "our scale is difficult for tarping, and [organic] mulch would be prohibitively expensive at our scale."

For most tillage operations, Burnt Rock Farm uses a 2.5 meter (8 ft) Farmet Softer* high-speed disk equipped with independently sprung, compound-angled, notched disks and a depth-setting rolling basket in the rear. Working 3-4 inches deep at a forward speed of 7-8 mph, the disk incorporates flail-mowed cover crops and makes a satisfactory bed for transplanting in two passes 10 days apart. Winter-killed cover crops require only one pass. Because the disk works best in moist soil, Justin incorporates mid-summer covers after a rainfall. H finds this implement less disruptive to soil structure than other tools such as the rototiller.

In a cropping system that depends on full-field tillage, "we must prioritize cover crops. We aim to keep something growing all the time, except for short fallows for weed control or to let incorporated residues decompose." Drawing on a toolbox of about eight different cover crop species, Burnt Rock Farm uses living plants to feed the soil life year-round, and rotates 10 of the 35 acres into full season cover each year.

* Mention of a trademark product is intended for information only and does not imply USDA or OFRF recommendation of this product over others.

Slides 54-56 – *Livestock-crop system with cover crop grazing at Keenbell Farm, Rockville, VA*

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

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

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

Slide 57 – *Nationwide cover crop info resources*

- Cover Cropping in Organic Farming Systems eOrganic articles and videos at https://eorganic.org/menu/872.
- National Center for Appropriate Technology – ATTRA Sustainable Agriculture Cover crops at https://attra.ncat.org/topics/cover-crops/.
- SARE Learning Center – Cover Crops Topic Room https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/.

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