Soil Health and Organic Farming

Practical Conservation Tillage

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ORGANIC FARMING RESEARCH FOUNDATION

SOIL HEALTH AND ORGANIC FARMING

PRACTICAL CONSERVATION TILLAGE

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

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Introduction

The Dust Bowl of the 1930s taught the US agricultural community a harsh and enduring lesson: tilled soil is vulnerable to erosion by wind and rain, and fragile soils cannot tolerate annual plowing without undergoing severe degradation. In addition to physically pulverizing the soil and exposing it to the elements, excessive tillage accelerates oxidation of soil organic matter and carbon dioxide emissions, disrupts important components of the soil food web, and can diminish the soil's capacity to hold water and nutrients. Even where favorable topography and climate minimize the loss of soil due to erosion, overtilled soils become less fertile, less resilient, and more prone to compaction as a result of the loss of organic matter (Figure 1). During the first half of the 20th century, growing concern with soil degradation gave rise to the soil conservation and organic farming movements to address soil erosion and declining soil health, respectively.

Figure 1. Soil disruption from tillage, USDA

Since the 1970s, increasing numbers of farmers have adopted no-till or reduced-till systems to curb soil erosion and improve soil health. In these systems, synthetic herbicides replace the plow, disk, and cultivation tools for seedbed preparation and weed control. Out of a total of 279 million acres planted to annual crops in 2012, no-till practices were implemented on 96 million acres and conservation tillage (leaving at least 30% surface cover by residues at the time of crop planting) on an additional 77 million acres (USDA NASS, 2014). Two NRCS working lands conservation programs—Environmental Quality Incentives Program (EQIP, established by the 1996 Farm Bill) and Conservation Stewardship Program (CSP, established by the 2002 Farm Bill)—offer financial and technical assistance for farmers to adopt and improve resource conservation practices, including no-till and conservation tillage on cropland acreage.

Organic farmers recognize healthy, living soil as the foundation of successful farming, and many seek practical means to reduce tillage in order to protect the soil organic matter, soil life, and improved tilth built up through green manures, compost applications and other organic practices. Without the use of herbicides, *continuous* no-till management is not practical for organic production of vegetables, grains, and other annual crops. A more realistic goal is to reduce the frequency and intensity of tillage in organic annual crop rotations. One approach is to terminate cover crops by non-tillage (mowing, roll-crimping), or minimum-tillage (strip tilling, undercutting) mechanical means, or through seasonal changes, usually winter freezes. After the cover crop is terminated, the farmer then plants the production crop without further tillage, and relies on cover crop residues to suppress weed growth until the crop is established (Figure 2). In this *rotational* no-till system, some tillage is conducted as needed after harvest to manage weeds and to plant the next cover crop.

Figure 2. Soybeans planted directly into rye cover crop residue, USDA

Organic no-till differs from conventional no-till in that the former requires a high-biomass cover crop that will leave sufficient residues to suppress weeds until the production crop is established. Whereas less than 10 percent of 173 million *total* US acres under no- or reduced-till is planted to cover crops (USDA NASS, 2014), essentially *all* organically managed rotational no-till acreage is cover cropped. Other organic conservation tillage systems usually include cover crops. For example, some organic practices include interseeding cover crops into standing vegetables or cereal grains (eliminates post-harvest tillage) (Burke et al., 2014; Ryan et al., 2016), and strip tillage or shallow full-width tillage of cover crops before vegetable or row crop planting (Chen et al., 2015; Gallagher et al., 2006).

Challenges in Organic Conservation Tillage

Successful organic rotational no-till depends on several key factors:

- Cover crops must attain *high biomass* (at least 3 tons/ac aboveground dry weight), and leave *persistent residues* that will suppress weeds until the production crop is established.
- Cover crops must be amenable to no-till termination. Sorghum-sudangrass, Japanese millet, some strains of hairy vetch, perennial cover crops, and any cover crop that has lodged (fallen over), may be difficult to kill without tillage or herbicides.
- Cover crops must be grown to *maturity* (full bloom to early seed formation) in order to be effectively terminated by roller-crimper or mower.
- Cover crops must not be *overmature,* or they may set viable seed, which can become a weed. The time window for termination can be narrow and may vary from year to year.
- Weed populations must be low to moderate, and must consist primarily of annual species whose emerging seedlings are readily blocked by the cover crop residue.
- Dates of cover crop maturity and termination must be compatible with timely planting of the subsequent production crop.
- Soil biology and overall soil health must be sufficient to allow timely mineralization (release) of nitrogen (N) and other nutrients to the production crop under no-till conditions, which may include lower temperatures, higher moisture, and less aeration.
- The grower must own or have access to suitable equipment for no-till cover crop termination and production crop planting.

Research into organic no-till and minimum-till has documented trade-offs between soil health and crop yields and profitability. Experimental systems that optimize soil health, nutrient retention, water quality, soil organic matter, and carbon (C) sequestration often suffer yield reductions related to reduced nutrient availability (especially N in corn), increased weed competition, incomplete cover crop termination, or inadequate seed-soil contact, which results in poor stands of production crops planted no-till into rolled cover crops (Barbercheck et al., 2014; Curran et al., 2014; Delate, 2013; Reinbott, 2015). The tradeoffs can be especially severe in the northern half of the US, where shorter growing seasons may not accommodate a cover crop grown to maturity without excessive delays in production crop planting (Barbercheck et al., 2008; Caldwell et al., 2012; Delate, 2013; Shapiro, 2013; Silva, 2015). Further south, longer growing seasons and faster N mineralization can facilitate organic no-till successes (Delate et al., 2015; Morse et al., 2007). Whereas conventional farmers can supplement the roller-crimper or mower with a low-dose herbicide application to ensure effective termination, currently available herbicides allowed under USDA Organic Standards (based on plant essential oils, fatty acids, or vinegar) are not cost effective for controlling cover crop regrowth or weeds at a field scale (Baker and Dyck, 2012).

One criticism of organic farming is based on the hypothesis that tillage and cultivation required for weed control degrades soil health and negates the benefits of cover cropping and other soil-building practices. Yet, studies in Washington (Cogger et al, 2013), Iowa, and Florida (Delate et al., 2015) documented substantial improvements in active soil organic carbon (C) and other soil health parameters from cover crops combined with compost applications, even in the full-tillage treatments, although reduced till (rotary spader or rotational no-till, respectively) further enhanced some soil health parameters. Additional studies have shown that regular, judicious tillage in the context of a diverse crop rotation and other organic practices can be compatible with soil building goals in organic farming (Dimitri et al., 2012).

NRCS has identified four key management principles for soil health (Kucera, 2015):

- Keep the soil covered as much as possible.
- Grow living roots throughout the year.
- Use diversity of plants to enhance soil microbial diversity
- Manage more by disturbing soil less.

Cover crop based conservation tillage systems can address all four of these. A conventional no-till corn-soy rotation without cover crops or with winter rye terminated at an early vegetative growth stage eliminates *physical* soil disturbance but provides less year-round soil coverage, reduced living root biomass, and lower crop diversity. Organic systems that include a sound and diverse crop rotation with attention to maintaining living plant and/or residue cover year round can address all four NRCS principles. Although physical soil disturbance is greater in these systems than continuous conventional no-till, *chemical* disturbance is greatly reduced by minimal use of soluble fertilizers and non-use of synthetic herbicides, insecticides, nematicides, and fungicides.

The practicality of reducing tillage in organic production can depend on region, climate, soil type, soil condition, farming system, crop mix, available equipment, and other factors. An additional challenge is determining whether a given system is actually improving soil health. Field kits, protocols, and soil health assessment sheets have been developed for producers and crop advisors to monitor soil health changes over time. However, active and total soil organic matter, soil food web functioning, potentially-available N, and other parameters of soil quality can be difficult to measure with sufficient precision to elucidate trends or document benefits. Yet, research to date, combined with producer experience, can offer some useful guidelines and ideas for maintaining soil health in organic annual crop production systems.

Practical Guidelines and Resources for Conservation Tillage in Organic Systems

Organic rotational no-till, in which some crops are planted into a preceding cover terminated by mowing, roll-crimping, or winterkill, can be challenging. Yet some producers and researchers have had success with this approach. Tips for enhancing the efficacy of no-till mechanical cover crop termination and subsequent cash crop production include the following:

- Allow the cover crop to reach full to late bloom before mowing or roll-crimping.
- Roll-crimp rye and other cereal grains in the soft-dough stage before seeds become viable.
- Roll-crimp a second time if needed to ensure complete termination *(see Case Study A, pg. 7)*.
- Choose cover crop varieties that mature early (e.g.,'Abruzzi' rye, 'Purple Bounty' hairy vetch), and are easily killed by roll-crimping *(see Case Study A, pg. 7)*.
- Use solarization or light exclusion to enhance cover crop termination in small scale operations such as intensive vegetable production, including:
  - Landscape fabric or opaque tarps for the first 2-4 weeks after roll-crimping or mowing, which can control weed and cover crop regrowth through the critical weed-free period of the following production crop *(see Table 1, pg. 15, item 3)*.
  - Solarization under clear plastic for a few days after mowing a high biomass cover cover crop in mid-late summer has given excellent results for no-till fall vegetable planting *(see Case Study B, pg. 9)*.

- Plant a cover crop in late summer that will develop substantial biomass, then die during freezing weather (winterkill), leaving residues into which early spring vegetables can be planted with no or minimal tillage *(see Table 1, pg. 15, item 14)*.
- No-till drill a production crop just *before* roll-crimping, which sometimes results in better seed-soil contact and hence better crop stands than planting into roll-crimped residues.
- Adjust or modify planting equipment to improve outcomes in your climate and soils, including:
  - Row cleaners to remove residue from seed rows.
  - Adding weight on the tool bar to penetrate residues.
  - Using different coulter type or other planter modifications.
  - Use finger weeders (Figure 3) and undercutters, which work better for weed control in the production crop than torsion weeders, spyders, or tines, which get tangled by heavy cover crop residues.

Figure 3. Finger weeders, UCCE Sonoma County

See Table 1, pg. 15: items 2, 3, 4, 5, 6, 7, 11, 12, 14, 15, and 16 for more on organic rotational no-till.

Case Study A

Choosing the Best Cover Crop Genetics for a Reduced-Tillage, Crop-Livestock Integrated System

Windy Acres Farm, the first certified organic grain farm in Tennessee, raises 422 acres of corn, soybean, cereal grains, pasture, and hay in a six-year crop rotation. The first three years consist of a corn-soy-winter cereal (wheat or barley) rotation, followed by three years in grass-legume-forbs sod cut for hay or managed for rotational grazing for their beef cattle herd.

“Cover crops are our most important crop,” presenter Holden Thompson noted, adding that the living root mass protects the soil and enhances water retention. At the end of the third summer in pasture or hay, they incorporate the sod with two passes with a heavy disk, and seed a fall cover of oats + hairy vetch (25 + 25 lb/ac) (Figure 4). The oats winterkill and vetch is grown until late spring and terminated by roller-crimper for no-till corn planting. The corn is followed by a winter cover crop of rye with a little vetch (150 + 8 lb/ac, respectively), which is roll-crimped for no-till soybean planting the following season. Fields are disked after soybean to plant winter wheat or barley, and again after grain harvest to seed pasture.

Figure 4. Oat and Hairy Vetch cover crop, Windy Acres Farm

“We grow and clean our own vetch seed, and have had success with roll-crimping,” Holden said. “If needed, we can roll-crimp a second time just as the corn emerges.” Managed this way, the vetch accrues more than 6,000 lb/ac biomass containing about 200 lb N, 20 lb P, and 200 lb K. None of the other legumes they have tried, including winter pea, crimson clover, and chickling vetch, have equaled hairy vetch for N fixation. Until about six years ago, they tilled the vetch a little earlier (at ~4,500 lb/ac), then switched to roll-crimping to reduce soil disturbance, and found that the surface residue also helped suppress weeds.

"There are many subspecies of hairy vetch, and they may vary in how easy they are to roll-crimp" Holden said. Timing is critical. They roll the vetch at full flower—at an earlier stage the roll-crimper does not kill the vines, and at a later stage the vetch sets too many mature seeds. "We are also looking at another variety, 'Purple Bounty,' which matures two weeks earlier." They plan to match it with 'Abruzzi' rye, which is believed to head out several weeks earlier than other rye varieties. They hope that these cultivars will allow earlier rolling and timelier planting of production crops.

When asked about vetch as a weed in cereal grain, the presenters noted that, after cleaning grain harvests in a Clipper Cleaner (some excellent 1950s technology), they use a spiral separator to sort wheat or barley from vetch, keeping the latter as part of their planting stock for the following season.

Figure 5. Pastures, Windy Acres Farm

Several other aspects of their integrated production system facilitate their success with rotational no-till. After cereal grain harvest, they seed a pasture mix of endophyte-free fescue, orchard grass, red and white clovers, and chicory, which is a copper accumulator and hence a natural wormer. Three years in pasture helps reduce weed populations in subsequent grain crops, which is important because the no-till cover crop management by itself "delays but does not eliminate weeds." They also raise a heritage breed of beef cattle ('British White'), which performs well on pasture and does not need grain. Finally, they avoid using fly tags on their cattle, because they also kill off dung beetles. Their pastures have sufficient dung beetle populations to degrade and incorporate manure with a few days after a grazing period, which further enhances soil health (Figure 5).

Based on a presentation entitled Growing Organic Grains to Sell, given by Alfred and Carney Farris and Holden and Rebekah Thompson of Windy Acres Farm (http://windyacrestn.com/) on January, 28, 2017, at the Southern SAWG Conference in Lexington, Kentucky.

Case Study B

Enhancing Cover Crop Termination and Nutrient Release for Fall Brassicas with Solarization

Anthony Flaccavento, farmer and consultant in sustainable economic development, grew a summer cover crop of pearl millet and cowpea in 2015, mowed it, then covered it with clear plastic for 48 hours (solarization), which resulted in complete cover crop termination. Fall broccoli planted immediately after solarization of this cover crop gave superb yields, with 1.3 – 2 lb heads, and showed no additional response to 90 lb/ac additional N as organic fertilizer (8-5-5). Yields after the cover crop slightly exceeded broccoli yields on bare ground (no cover crop) with 180 lb N as organic 8-5-5. Given the difficulty in delivering adequate N to organic broccoli, documented in Virgnia (Morse et al., 2007) and California (Li et al., 2009), this is a noteworthy success.

Based on an interview with Anthony Flaccavento of Abingdon, VA, conducted in 2015.
Anthony can be reached at flaccavento@ruralscale.com.

Other ways to reduce tillage intensity in organic cropping systems include the following:

- Implement an ecologically based integrated organic weed management strategy to reduce the need for tillage and cultivation to control weeds.
- Add a perennial sod break (2 years or more) to an existing annual crop rotation to allow for soil restoration and depletion of the weed seed bank.
- Integrate crops with rotationally-grazed livestock to further enhance nutrient cycling, economic returns from the sod phase, and soil C sequestration *(see Case Studies A and D)*.
- Overseed or interseed cover crops into standing vegetable or grain crops to eliminate post-harvest tillage *(see Table 1, pg. 15, items 9d and 15)*.
- Use tillage tools and methods that minimize damage to soil structure and SOM, as follows:
  - Run rototiller at a slower rotary speed combined with faster forward speed to minimize destruction of soil aggregates *(see Case Study C)*.
  - Shallow conservation tillage (e.g. rotary harrow) that leaves some residue on the surface and leaves soil structure and root residues intact deeper in the soil profile.

- Ridge tillage *(see Table 1, pg. 15, items 9a, 9b,9c, and 15)* or strip tillage with row cleaners to prepare seedbed in crop row, leaving alleys undisturbed (Figure 6 and 7).
- Rotary or reciprocating spader in lieu of plow-disk or rototiller to incorporate cover crops and prepare the seedbed *(see Table 1, pg. 15, item 15 for video clip)*.
- Sweep-plow undercutter to terminate the cover crop and disrupt emerging weeds while leaving much of the soil profile undisturbed.

Figure 6. Soybeans planted into ridge tilled corn residue https://www.nrcs.usda.gov/Internet/FSE_MEDIA/nrcs144p2_026395.jpg

Figure 7. Peanut crop growing in strip tilled field, USDA

See Table 1, pg. 15: items 1, 4, 5, 8, 9, 10, 11, 13, and 15 for more on organic reduced till strategies. Item 17 in Table 1, pg. 15, provides a thorough and balanced discussion of the advantages and drawbacks of wide range of tillage tools and practices (full till to no-till) in organic system.

For more on organic weed management, see Weed Management: An Ecological Approach. For more on cover crops, see Cover Crops: Selection and Management.

Case Study C

Rotary Tillage Geared Down for Soil Health

Figure 8. Mattawoman Creek Farm

Rick Felker grows 44 acres of certified organic greens and other vegetables at Mattawoman Creek Farm on the Eastern Shore region of Virginia (Figure 8). He outlined keys to his successful system for producing greens and maintaining soil quality on the farm's loamy-sand soils.

The farm uses a permanent raised bed system in which the bed tops have received no traffic since 2005, thereby eliminating soil compaction. Rick plants winter rye + hairy vetch cover crops on beds and traffic alleys at the end of October, the best planting date for weed suppression, winter coverage, and biomass in his Zone 7b/8a climate. In spring, the cover is flail-mowed, followed by a disk bedder to rebuild beds and move residues into the grow zone.

Next, fields are tilled gently, using a lower gear on the rototiller and driving the tractor at about 2.5 mph. Rick noted that many farmers overtill their fields by driving at about 1 mph with the rototiller in high gear. His approach incorporates cover crop residues about 4 – 6 inches deep, yet allows visible crumb structure to develop in the farm's sandy soil.

Most crops are transplanted into the field, using a waterwheel transplanter (Figure 9). Transplanted crops get a jump on weeds, and do not require as fine a seedbed as direct seeding.

Figure 9. Planting starts at Mattawoman Creek Farm.

https://www.facebook.com/Mattawoman-CreekFarms/photos/a.226498364028017.72050.128034863874368/1124878360856675/?type=3&theater

Drip tape is laid sub-surface at a depth of 3.5 inches to allow for shallow cultivation and promote downward growth of plant roots, which improves root development and thus drought tolerance. High density planting is used for most crops to maximize production and harvest efficiency, and promote canopy closure and weed suppression. The higher density and depth of production crop roots may also contribute to soil organic matter and soil health in this system.

Based on a presentation, entitled Growing Healthy Greens, given by Rick Felker (https://www.mattawomancreekfarms.com/) at the Virginia Biological Farming Conference on January 30, 2016.

Case Study D

Reducing Tillage through Crop Rotation and Crop-Livestock Integration in Intensive Organic Vegetable and Field Crop Production

Elmwood Stock Farm produces beef, pork, lamb, chicken, turkey, eggs, and a wide range of vegetables for a 400-family CSA, nearby school food programs, restaurants, and other markets (Figure 10). Producing both vegetables and animal products for market has created an opportunity to develop an eight-year crop-livestock integrated rotation for their 200 tillable acres. Three years of annual crops (35 acres vegetables, 35 acres feed grain crops for the pigs and poultry each year) are followed by five years in grass-legume sod. The vegetable rotation is as follows:

Figure 10. Elmwood Stock Farm at a farmers' market, Elmwood Stock Farm

- Year 1 – sod is moldboard-plowed in late February or early March, followed by "high demanding, long season, high value crops" such as tomato, potato, squash, and cucumber.
- Year 2 – cool season root crops, brassicas, and greens are grown in spring, and are either double cropped with fall vegetables or followed by fall cover crops.
- Year 3 – "after two years of intensive row cropping and tillage, we figure the soil is getting tired," so nitrogen-fixing legume vegetables like peas, green or dry beans, cowpeas, and edamame are followed by re-seeding perennial grass-legume sod.
- Years 4-8 – grass finished beef and other livestock are pastured in a mob-grazing system, in which brief grazing at a high stocking rate is followed by a long recovery period.

The field crop rotation begins with grain corn after breaking sod, and soybean and winter cereal grain in years 2 and 3, then seeded to pasture after wheat or barley harvest. In addition, the remainder of the 550 acre farm—areas where slopes are steeper or soil quality is not as good—is kept in permanent pasture, for rotational grazing.

"Crops and livestock raised together are the key," Ann and John stated. "Ruminants are a profit center, but just as importantly they are the soil building fertility for the high value row crops, both feed grains and vegetables." Manure and trampled forage left by mob-grazed cattle provide optimum fertility, rejuvenate the soil, and cut off-farm input costs to a minimum. "We bought only 200 lb fertilizer in 2016 for the entire farm," John noted. They make on-farm compost from vegetable culls, old hay, and a little poultry litter, and use most of it in the greenhouse for vegetable start production.

Elmwood Stock Farm is participating with University of Kentucky in a multi-year study of soil health in their eight-year rotation, in comparison with the permanent pasture. The first year of data, taken in Year 4 of the rotation, showed soil biological activity, organic matter, and organic N "approaching that of the permanent pasture."

Three keys to their success include:

- The long sod break allows the soil to recover fully from three years intensive cropping with tillage.
- The living plant is the primary engine of soil health and fertility in this system. Both on-farm compost and off-farm inputs (lime, fertilizer, a little feed grain) are used as supplements.
- Livestock-crop integration greatly enhances nutrient cycling and efficiency, as well as building soil organic matter and soil life through mob-grazing.

Based on a tour of Elmwood Stock Farm (http://elmwoodstockfarm.com/) in Scott County, Kentucky, given on January 26, 2017, by farmers Ann Bell Stone and John Bell, in conjunction with the annual Southern SAWG conference in Lexington, Kentucky.

Table 1. Resources on Conservation Tillage in Organic Systems

1. **Risk Management Guide for Organic Producers** (K. Moncada and C. Sheaffer, 2010, University of Minnesota, 300 pp) Chapter 13, Winter Cover Crops, includes region-specific recommendations for no-till and minimum-till cover crop termination in corn-soy-wheat rotations in the upper Midwest. http://organicriskmanagement.umn.edu/.

2. **Offing Cover Crops for Weed Suppression: Featuring the Roller Crimper and Other Mechanical Contraptions**, (University of Maryland, 2014)* https://extension.umd.edu/learn/offing-cover-crops-weed-suppression-featuring-roller-crimper-and-other-mechanical-contraptions. Opportunities, limitations, and practical tips for roller-crimper and other non-chemical no-till cover crop termination methods.

3. **Organic Weed Control in No-Till Systems**, (G. Brust, University of Maryland, 2014)* https://extension.umd.edu/sites/default/files/_docs/articles/OrganicWeedControlUsingNo-till_3-2014_0.pdf. Practical recommendations for using weed mat (landscape fabric) on roll-crimped cover crop to enhance no-till efficacy in small scale vegetable production.

4. **Lessons Learned from a Reduced-Tillage Organic Cropping Systems Project**. (W. Curran, R. Huber, and J. Wallace, Pennsylvania State University, 2014). Webinar at: http://articles.extension.org/pages/70428/webinar:-lessons-learned-from-a-reduced-tillage-organic-cropping-systems-project; powerpoint slides as pdf file at: www.eorganic.info/sites/eorganic.info/files/u461/eOrganic-Curran_Final_0.pdf.

5. **Reduced-tillage Organic Systems Experiments (ROSE).** Pennsylvania State University, http://agsci.psu.edu/organic/research-and-extension/rotational-no-till, includes links to reports from completed and ongoing projects including an update of *The Reduced Tillage Toolbox* covering the 2016 growing season at: http://agsci.psu.edu/organic/research-and-extension/rotational-no-till/publications/rose-review-winter-2017.

6. **What is "Organic No-till," and Is It Practical?** (M. Schonbeck, 2015). Article outlining the basic practice of cover crop based rotational no-till in organic vegetables. http://articles.extension.org/pages/18526/what-is-organic-no-till-and-is-it-practical.

7. **Rotational No-till and Mulching Systems for Organic Vegetable Farms** (J. Cropp, 2015). Webinar based on farming system developed in Germany but widely applicable. http://articles.extension.org/pages/71822/rotational-no-till-and-mulching-systems-for-organic-vegetable-farms-webinar.

8. **Reduced Tillage in Organic Vegetable Production: Success, Challenges, and New Directions** (H. Atthowe, 2011). Webinar at: http://articles.extension.org/pages/61629/reduced-tillage-in-organic-vegetable-production-webinar.

9. **Organic Cropping Systems Project** at Cornell University, http://www.hort.cornell.edu/extension/organic/ocs/, especially:

   a. *Vegetable Experiment*, including ridge-till in vegetable systems. http://www.hort.cornell.edu/extension/organic/ocs/vege/index.html.

   b. *Organic Ridge Till Vegetables* (K. Isaacs, B. Caldwell, C. A. Mohler, 2007) www.hort.cornell.edu/extension/organic/ocs/vege/pdfs/2007vegridgettill.pdf.

   c. *Economic Performance of Organic Cropping Systems for Vegetables in the Northeast*. (S. B. Chan, B. Caldwell, B. Ricard, and C. Mohler, Cornell U, 2011). http://www.hort.cornell.edu/extension/organic/ocs/vege/pdfs/economic_performance.pdf.

   d. *Cover Crop Interseeding Research in New York*. (Brian Caldwell, Chris Pelzer, and Matthew Ryan, Cornell U., 2016). Trials with cover crops interseeded into corn and soybeans, preliminary recommendations, link to vendor of Interseeder implement. http://blogs.cornell.edu/whatscroppingup/2016/03/15/cover-crop-interseeding-research-in-new-york/.

10. **Transition from Conventional to Organic Farming using Conservation Tillage** (D. L. Wright, I. M. Small, and T. W. Katsvairo, University of Florida, 2016). Detailed recommendations for organic vegetable production in Florida. http://edis.ifas.ufl.edu/ag246.

11. **Soil Health in Organic Farming Systems**, video presentation available at Organicology 2015: Selected Live Broadcasts and Recordings from the Conference, includes no-till and reduced till. http://articles.extension.org/pages/72568/organicology-2015:-selected-live-broadcasts-and-recordings-from-the-conference.

12. **Cover Crops and No-Till Management for Organic Systems.** Rodale Institute information sheet, 2011. http://www.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/Cover-Crops-and-No-Till-Management-for-Organic-Systems.

13. **Adoption Potential and Perceptions of Reduced Tillage among Organic Farmers in the Maritime Pacific Northwest**. (A. T. Corbin, D. P. Collins, R. L. Krebill-Prather, C. A. Benedict, and D. L. Moore, Washington State U., 2015.). Farmer perspectives based on focus groups. http://articles.extension.org/pages/68283/adoption-potential-and-perceptions-of-reduced-tillage-among-organic-farmers-in-the-maritime-pacific-.

14. **Using Winter Killed Cover Crops to Facilitate Organic No-till Planting of Early Spring Vegetables Webinar.** (C. White of Pennsylvania State U, and M. Snow of Accokeek Foundation. 2012). http://articles.extension.org/pages/31013/using-winter-killed-cover-crops-to-facilitate-organic-no-till-planting-of-early-spring-vegetables-we.

15. **Cover Cropping in Organic Farming Systems**, eXtension web page at http://articles.extension.org/pages/59454/cover-cropping-in-organic-farming-systems. See especially the **video clips** on frost seeding and interseeding cover crops, ridge till, strip till, high residue reduced till systems, and soil spader for cover crop incorporation.

16. **Soil Health in Organic Farming Systems**, webinar (Mark Smallwood of Rodale Institute, Doug Collins of Washington State University, Ben Bowell of Oregon Tilth and NRCS, 2015). Field studies comparing soil condition and vegetable yields in no-till, strip-till, and spaded cover crops in Pacific Northwest (cool, moist climate). http://articles.extension.org/pages/72568/organicology-2015:-selected-live-broadcasts-and-recordings-from-the-conference.

17. **Use of Tillage in Organic Farming Systems: The Basics** (Joel Gruver, Western Illinois U; and Michelle Wander, Illinois State U, 2015). Thorough discussion of a wide range of tillage options in organic systems. http://articles.extension.org/pages/18634/use-of-tillage-in-organic-farming-systems:-the-basics.

* Access via https://extension.umd.edu/mdvegetables/organic-vegetable-production

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

Continuous No-Till: Not Required for Soil Building in Organic Systems

Continuous no-till does not appear practical for many organic cropping systems. For example, organic sweet corn had greatly reduced yields in a continuous no-till system in North Carolina, despite improving soil quality, primarily because of weed pressure (Osmond et al., 2014). However, judicious tillage can be compatible with soil improvement in organic systems (Dimitri et al., 2012). In organic vegetable crop rotations in Iowa and Florida winter cover crops enhanced soil microbial activity, increased storage of active and total soil organic C and N, and reduced N leaching. Composted manure applications also contributed to microbial activity and organic C and N, while rotational no-till improved soil structure. Notably, most of these benefits accrued "regardless of whether the cover crop [was] tilled or roller/crimped prior to vegetable transplanting" (Delate et al., 2015).

In the challenging semiarid environments of Wyoming and western Nebraska, organic no-till systems had severe yield tradeoffs (Norton et al., 2014). However, a reduced tillage organic transition strategy that included one summer tillage pass did not negate soil health benefits of organic practices in dryland wheat or irrigated cropland (Ibid.). One innovative approach, explored over multiple seasons in the High Plains region of Montana, is to integrate sheep into organic dryland grain, pulse, and oilseed production (Menalled et al., 2016). Efforts to replace all tillage with targeted sheep grazing to manage green manures and weeds led to severe (45-90%) yield reductions in wheat and dry pea, mostly owing to heavy infestations of aggressive perennial weeds, especially field bindweed and Canada thistle (Ibid.). The research team is now working with a modified system that integrates sheep grazing and crops with a 50-60% reduction in tillage frequency; and the first year gave more encouraging results with little yield reduction in wheat and a 30% reduction in lentil (Menalled, 2016).

In a study of soil food web biodiversity and community structure under organic versus conventional systems with full tillage or conservation tillage, both organic methods and reduced tillage generally enhanced the soil food web (Epstein, 2007). Species richness and abundance of several functional groups, especially predatory nematodes and mites, were greater in organic systems (conservation or full till) than in conventional full till.

No-Till Mechanical Termination of Cover Crops: Rotational Organic No-Till

In trials conducted at 11 sites in six northern states (North Dakota, Michigan, Iowa, Wisconsin, and Pennsylvania) rotational no-till systems were compared with conventionally tilled systems. The no-till system, in which corn was planted into roll-crimped hairy vetch and soybean into roll-crimped rye, resulted in enhanced soil aggregation, microbial biomass, active organic matter, potentially mineralizable N, and extractable K over a four-year period, compared to conventionally tilled systems with the same crop rotation (Delate, 2013). However, corn yields were reduced by 63% in the no-till system because of winterkill and low biomass in vetch covers, N limitation, and weed competition. Spring oats planted after corn suffered severe competition from perennial weeds resulting again in a 63% yield loss, and soybeans planted in roll-crimped rye yielded 31% less than in the tiled system.

Hairy vetch-triticale and hairy vetch-rye winter cover crops produced sufficient biomass for organic no-till corn and soybean planting in Pennsylvania, Maryland, and Delaware, and two well-timed passes with the roller crimper were recommended to ensure effective termination (Barbercheck et al, 2014). Soybean yields in roll-crimped winter cereal rye were equal to or greater than yields after a tilled cover. However, significant yield reductions were observed in corn after roll-crimped versus tilled covers (Barbercheck, 2016; Barbercheck et al., 2014). Similarly, soybeans yielded well while corn showed yield depression in organic rotational no-till in Missouri (Clark, 2016). Good weed suppression and high yields were also reported in organic soybean planted no-till into roll-crimped rye, triticale, or barley in upstate New York (Caldwell et al., 2016).

In coastal Washington State (cool, wet climate), no-till or strip till squash and brassicas (planted after cover crops were flail mowed or roll-crimped) yielded as well or better than after crops were tilled in sandy soils, but the no-till and strip till gave very poor yields in heavier (silt-loam) soils (Collins et al, 2015).

Light exclusion with opaque tarps or similar materials can provide a practical means to enhance cover crop kill and weed suppression in small scale no-till or minimum-till vegetable production. Laying weed mat (landscape fabric) immediately after roll-crimping a cover crop for two weeks before planting a vegetable crop can effectively suppress weeds and cover crop regrowth. This was demonstrated in organic tomato production in Maryland, in which weeds were suppressed for an additional eight weeks after the landscape was removed, leading to practical recommendations for the practice (Brust, 2014). In upstate New York, on-

One challenge with organic minimum till systems is managing weeds that emerge after production crop planting.

farm trials demonstrated successes with oats grown for eight weeks, mowed, and covered with opaque plastic tarps for three to four weeks before planting fall cabbage (Rangarajan, 2016). In addition, landscape fabric was laid over mowed cover crops in narrow-strip-till planted winter squash. In both crops, the experimental treatment gave weed control and vegetable yields similar to full-width tillage with the same light exclusion treatment (Rangarajan, 2016).

One challenge with organic minimum till systems is managing weeds that emerge after production crop planting. Finger weeders worked fairly well for in-row weed control in the presence of heavy cover crop residues in on-farm trials, while torsion weeders and spyders became tangled in residues and performed poorly (Rangarajan, 2016). A HAK cultivator combining three different tools (an undercutting tool followed by finger and tine weeders) also proved effective for in-row weeding of reduced-till organic crops. Further refinement of both tarping and cultivation techniques is planned for the remaining two years of the project.

Organic rotational no-till systems may be more practical in regions with longer growing seasons. In Virginia and Georgia, no-till management of sufficiently high-biomass winter annual cover crops (~3 tons/ac aboveground dry weight or more) gave adequate weed suppression and broccoli, squash, and pepper yields equivalent to the tilled cover crop, although vegetable yields were lower under no-till conditions in two site-years (Morse et al., 2007). Kloepper et al. (2010) reported "an effective organic no-till method for tomato and pepper" in Alabama that entailed surface applications of compost over roll-crimped covers. Crop yields varied from similar to somewhat less than in the tilled treatments. Melon, a crop that requires warm soil, showed sharply reduced yields in cooler, wetter soil conditions under roll-crimped cover crop in Maryland (Micallef, 2016).

In Florida, pac choi and summer squash yielded well in roll-crimped sunnhemp cover crop residue, whereas in Iowa, sweet corn and tomato showed some yield reduction in roll-crimped versus tilled rye and vetch cover crops (Delate et al., 2015). No-till cover crop termination enhanced the soil aggregation and N retention benefits, of the cover crop. The researchers concluded that "in Florida's sandy soils, organic no-till holds the most promise because of the potential for early cover crop planting, continuous cover crop growth over the year, and earlier termination dates" (Delate et al., 2015). In Hawaii, green onions planted no-till into mowed sunnhemp yielded better and had fewer insect pests than the same crop grown in bare ground or plastic mulch after sunnhemp was tilled in (Chen et al., 2015).

Researchers at the University of Missouri found that planting a cash crop into standing cover just before roll-crimping can enhance seed-soil contact and subsequent cash crop stands compared to no-till planting into rolled cover crops (Reinbott, 2015). Soybean in particular emerged and produced high yields when planted into rye just before roll-crimping (Clark, 2016).

Other Approaches to Reduce Tillage

Strip tillage, in which the cover crop is incorporated in a narrow strip centered on the planting row of the production crop and left on the surface between rows, has provided positive economic returns and soil health benefits (organic C and N, aggregation) in organic vegetables in Maryland (Chen et al., 2015). In Florida, two or more years in bahiagrass sod followed by annual cover crops managed with strip tillage increased soil organic matter and reduced fertilizer and water needs in subsequent vegetable crops (Andersen et al., 2014). While the strip till treatment sometimes gave yields equivalent to conventional tillage, a rotation of three years bahiagrass sod followed by green bean and broccoli production with winter (oats + rye) and summer (soybean) cover crops showed the highest potential economic return and lowest risk (Ibid.)

In a study of reduced tillage organic vegetable production systems, ridge tillage gave promising results when perennial weed populations were low (Drinkwater et al., 2014). In ridge tillage, crops are planted on ridge tops that are shallowly tilled to remove weeds and residues and prepare the seedbed, with no tillage between the ridges. Compared with other systems involving either full tillage or an alternation of production and green fallow (cover crop) years, ridge till gave lower net returns in potato, similar net returns for lettuce and cabbage, but higher net returns in winter squash (Chan et al., 2011).

Overseeding a cover crop into a standing production crop can eliminate a tillage pass without incurring the risks associated with planting into a roll-crimped cover. In a corn-soy-spelt rotation in PA, timothy and red clover were overseeded into spelt and terminated by plowing before corn. This lengthened the growing season for the cover crop, reduced N leaching, and improved corn yields by 11 bushels/ac, compared to triticale-hairy vetch cover seeded after spelt harvest and plowed down for corn grain or roll-crimped for corn silage (Barbercheck, 2016). In addition, ryegrass and forage radish were successfully interseeded into standing corn in these trials.

In upstate New York, various annual cover crops interseeded into corn at the 5-7 leaf stage established and provided greater fall-winter soil protection than would be feasible with post-harvest planting (Caldwell et al., 2016; Ryan et al., 2016). Cover crop performance varied widely among species as well as by season. Overall, best results were observed with ryegrass and clover interseeded in soybean ahead of corn, and ryegrass alone in corn ahead of soybean.

Comparison of Tillage Treatments

In Nebraska, legume-mustard cover crop mixtures planted in late March and terminated in late May with a sweep-plow undercutter left much of the residue on the surface, conserved moisture, reduced weed numbers, and enhanced corn and soybean yields by 17% and 23% respectively compared with the no-cover control (Wortman et al., 2016, Figure 11). In contrast, terminating the same cover crops by disking accelerated soil moisture loss and reduced soybean yields by 14%.

Figure 11. Legume-mustard cover crop seed mixture, The Howdy Farm at Texas A&M University

In Pennsylvania, a reduced till treatment consisting of chisel plowing as primary tillage in a corn-soy rotation with cover crops resulted in improved soil aggregate stability, moisture-holding capacity, labile organic C, and micro-arthropod populations compared to moldboard plowing (Barbercheck et al., 2008). However, corn yields and overall profitability were better in the full tillage (moldboard plow) treatment (Barbercheck et al., 2008).

In organic vegetable rotations with cover crops in the Pacific Northwest, using a rotary spader to make seedbeds in lieu of moldboard plow, disk, and rototiller consistently reduced soil compaction (Cogger et al., 2013). Rotary spading also enhanced yields in five out of 26 vegetable crops over a five-year period.

Finally, organic crop rotations that alternate several years of annual crop production with routine tillage with two or more years of grass or grass-legume sod can be quite effective in restoring and maintaining soil quality. Examples from USDA funded organic research include three years of bahiagrass in rotation with broccoli and green bean (Anderson et al., 2014), two years of alfalfa in corn and soybean production (Delate et al., 2014), and three years of perennial sod prior to tomato and edamame soybean in the fourth and fifth years (Eastman et al, 2008). In addition, many organic farmers with sufficient acreage have adopted such rotations with excellent results (see Case Studies A and D).

Questions for Further Research Toward Practical Reduced-Tillage Systems for Soil Health in Organic Production

Additional research leading to practical tools and guidelines that can help organic producers reduce tillage is clearly warranted. Uneven results with organic rotational no-till indicate a need for more work to develop improved tools and methods. Other approaches, including lower-impact tillage tools and practices such as sod breaks in the rotation and crop-livestock integration, have yielded promising results. Further studies and field demos can fine-tune these strategies for implementation in a wider range of agro-ecoregions and farming systems.

Approaches to organic conservation tillage must also be regionally adapted. For example, warm, rainy regions and semiarid regions present different challenges and opportunities from the North-Central and Northeast regions where much of the organic reduced-tillage research has been conducted to date. Soils in the Southern region are especially subject to organic matter oxidation, and it can be especially difficult to achieve a positive value in the NRCS Soil Conditioning Index (SCI) used to evaluate soil impacts of production systems. Yet, the longer growing season increases opportunities for high biomass cover crops that can help replenish organic matter and maintain soil health. In semiarid regions, dryland farmers face moisture constraints that limit capacity to integrate cover crops into rotations, or to grow sufficient cover crop biomass to suppress weeds and build soil organic C and N.

Specific Priorities for Additional Research in Organic Conservation Tillage

- Practical systems and guidelines for organic conservation tillage in different agro-ecoregions to address unique challenges of semiarid, warm-rainy, cold-short-season, and other regions. This requires a regional approach to each of the following topics.
- Improved tools, crop cultivars, and practices for organic rotational no-till and mulch-till (≥30% residue cover at planting) that minimize "yield drag" and improve net profits:
  - Breeding and selecting cover crops for high biomass, lodging-resistance, timely maturity, and ease of termination by roll-crimping or mowing.
  - Breeding and selecting production crops to perform well in organic no-till: cold germination, seedling vigor, N use efficiency, and weed competitiveness.
  - Improved equipment and methods for cover crop termination, no-till planting, and interseeding cover crops into standing production crops.
  - Improved high residue cultivators, and other weed management tools for cover crop based no-till and reduced-till systems.
- Degree of reduction in tillage needed to build and maintain satisfactory soil health.
- Tillage tools and methods that minimize adverse impacts on soil health compared to "standard" practices such as plow-disk or rotary tillage.
- Potential for organic cropping systems that integrate routine tillage with other practices and inputs to build and maintain desired soil health.
- Perennial sod breaks and crop-livestock integration, including optimum length and species composition of the sod phase, and optimum grazing management for soil health as well as short and long term economic returns.

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