Reduced Tillage in Organic Systems Field Day   Program Handbook

July 31, 2018 at Cornell University Willsboro Research Farm, Willsboro NY

Cornell University
Cooperative Extension

Welcome to our

Reduced Tillage in Organic Systems Field Day

July 31, 2018

Cornell University Willsboro Research Farm

48 Sayward Lane, Willsboro, NY 12996

Speaker contact information:

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John Wallace - Cornell University Weed Ecology and Management
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Many thanks to our funders:

NY Soil Health	http://newyorksoilhealth.org/
Lake Champlain Basin Program	http://www.lcbp.org/
Northern NY Agricultural Development Program	http://www.nnyagdev.org/

This program was coordinated by CCE Eastern NY Commercial Horticulture Program, CCE Essex County, and the Cornell University Willsboro Research Farm.

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Carly Summers – cfs82@cornell.edu 518-962-4810 CCE Essex County

Reducing Tillage in Organic Systems Field Day

July 31, 2018

Agenda

9:00-9:30	Registration
9:30-9:40	Welcome and Introductions
9:40-10:20	First Round of 3-Stations
10:20-11:00	Second Round of 3-Stations
11:00-11:40	Third Round of 3-stations
11:40-12:45	Lunch
12:45-1:25	First round of 3 aft stations
1:25-2:25	Second round of 3 aft stations
2:25-2:45	Third round of 3 aft stations
2:45-3:00	Wrap up, evaluation, final discussion
3:00-4:00	Speakers will remain for informal discussions as needed

	Station	Topic	Speakers
Morning Sessions	1	Crimpers	Jean-Paul Courtens-Roxbury Farm Kitty O'Neil-No Country Ag Team
	2	Cover crops, low residue tillage	Heather Darby – University of Vermont Mike Davis – Cornell Willsboro Farm Chuck Bornt - ENYCHP
	3	Cultivation	Bryan Brown NYS IPM Program
Afternoon Sessions	4	Zone tillage systems in high residue	Ryan Maher Cornell Small Farms Program
	5	Weed mgt strategies	John Wallace - Cornell University Chuck Bornt - ENYCHP
	6	Reducing tillage on my farm	Jack Lazor – Butterworks Farm Heather Darby – University of Vermont

Lake Champlain Basin Program · New York Soil Health · Northern New York Agricultural Development Program

Cornell Cooperative Extension
Eastern NY Commercial Horticulture Program

Reduced Tillage in Organic Systems *Field Day*

Featuring in-field demonstrations of equipment and discussions with speakers and growers Rotate between 3 demonstration/discussion stations in the morning, 3 more in the afternoon.

Topics include: *roller-crimping, zone tillage in high residue, in-row cultivation tools, stale seedbed and weed seed bank management strategies with an overall focus on soil health.*

Tuesday, July 31st 9:00am—3:00pm
(Speakers will stay until 4:00 to continue discussion as needed)

Cornell Willsboro Research Farm
48 Sayward Lane
Willsboro, NY 12996

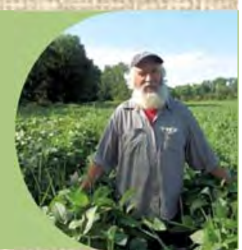
Free to the Public, Lunch included!
First 50 attendees will receive a program resource booklet, (also available online after the event)
Please register at https://enych.cce.cornell.edu/event.php?id=953

Questions? Contact Amy Ivy, adi2@cornell.edu 518-570-5991 or Carly Summers, cfs82@cornell.edu 518-962-4810 x409

Coordinated by the Eastern NY Commercial Horticulture Program, CCE Essex County and the Cornell Willsboro Research Farm
with funding from NY State Soil Health Initiative & Lake Champlain Basin Program , Northern NY Ag Development Program

Featured Speakers:

Jack Lazor
Butterworks Farm
Westfield, VT



Mike Davis
Cornell Willsboro Research Farm Manager

Jean-Paul Courtens
Roxbury Farm,
Kinderhook NY

Heather Darby
University of Vermont Agronomist

Additional Speakers:

Kitty O'Neil, CCE North Country Regional Ag Team
Ryan Maher , Cornell Small Farms Program
Bryan Brown, NYS IPM Program Integrated Weed Mgt
John Wallace, Cornell Weed Ecology & Mgt Professor
Chuck Bornt , CCE Eastern NY Commercial Horticulture

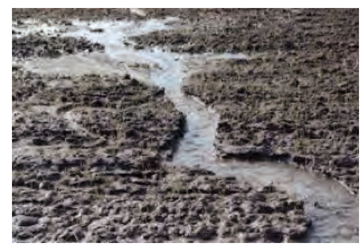
NEW YORK SOIL HEALTH

Current Priorities and Plans for 2018-2019

New York Soil Health for Healthy Food, Profitable Farms, and Protection of Natural Resources

Poor soil health has economic and environmental costs

Loss of soil organic matter leads to unhealthy soils, which become less resilient to weeds, pests, and drought, and more prone to flooding and soil erosion. Rebuilding soil organic matter increases farm profitability, and has environmental co-benefits, such as reducing chemical runoff into waterways, and storing carbon in soils that otherwise would be in the air as the greenhouse gas, carbon dioxide.



Partnerships addressing constraints to improved soil health practices

Interest in soil health practices such as reducing tillage, planting winter cover crops, and using compost amendments has expanded greatly in recent years, yet constraints to adoption persist. This state-funded project facilitates collaboration among the many on-going efforts across the state to implement research, outreach, and policy solutions to address these constraints.

Plans and Key Accomplishments

- *Quantifying economic and environmental benefits.* A statewide survey has been completed to identify costs and benefits of soil health practices. Publication expected Fall 2018. Results will inform a more detailed analysis in collaboration with USDA-NRCS economists, farmers, and others.
- *Strengthen partnerships and outreach.* Since April 2017 we participated and supported over 20 workshops, field days, and conferences, including the NE Cover Crops Annual Meeting and a soil health session at the Producers Expo in Syracuse. A website has been established, and new curricula, resources, and a statewide communication strategy are being developed.
- *Soil Health Roadmap and Summit.* Farmers and other stakeholders from over 10 organizations and businesses are participating in the visionary "Roadmap" document. The first statewide Soil Health Summit will be held July 18, 2018.

- *Innovative cropping systems research*. Soil health and productivity effects of a long-term organic systems project, and results of an apple orchard ground cover study, are being analyzed and prepared for publication. Future research plans include: evaluation of perennial grains; co-benefits of cover crops for white mold disease suppression; addressing unique challenges for vegetable crops; and key soil health indicators for apple orchard management.

- *Evaluation of composts and biochar soil amendments*. These studies involve optimizing compost mixes to remediate degraded soils, and upscaling a process for nutrient fortification of biochar with dairy manure waste.
- *Soil health and natural climate solutions.* An analysis of potential climate change mitigation benefits associated with improved soil carbon and nitrogen management is underway and will be completed by March 2019.

For more information: newyorksoilhealth.org

NEW YORK STATE OF OPPORTUNITY. Agriculture and Markets

Cornell CALS College of Agriculture and Life Sciences

USDA United States Department of Agriculture
Natural Resources Conservation Service

b

Survey of Costs, Constraints, and Benefits of Soil Health in NY: Initial Report & Summary

Cedric W Mason & David W Wolfe
Cornell University

This survey of farmers in New York state was conducted during the winter of 2017-18 by New York Soil Health to 1) prioritize the most common costs and benefits experienced by farmers who use soil health practices, 2) explore how these costs and benefits change over time, and 3) evaluate and compare the performance of several different practices and cropping systems.

182 responses were received from farmers representing 46 different NY counties and approximately 172,000 acres of cropland. The two most commonly reported constraints on crop production were "Poor drainage" and "Soil Compaction", which were identified by more than 60% of farmers. The third most common constraint was "Soil erosion", which was identified by just over 40% of farmers. Other production constraints included "Low soil fertility" and "Inadequate water retention".

Highlights:

- Averaging across all cropping systems, greater yields were reported by 52% of the reduced tillage group and by 50% of the cover crop group (Table 1, Table 2), while lower yields were reported by 10% and 3% respectively.
- Of farmers who used reduced tillage or cover crops, over 60% reported that flooding prevention, drought resilience, and less erosion resulted from these practices (Fig. 1).
- Some of the costs and benefits of cover crops and reduced tillage were associated with the length of time that farmers had been using those practices (Fig. 2).
- Vegetable growers experience different costs and benefits as a result of their cover crop and reduced tillage practices, compared to corn and/or soybean growers (Table 2).
- Both cover crops and reduced tillage were reported to be profitable by the majority of practitioners, while less than 5% reported a negative effect on profitability.

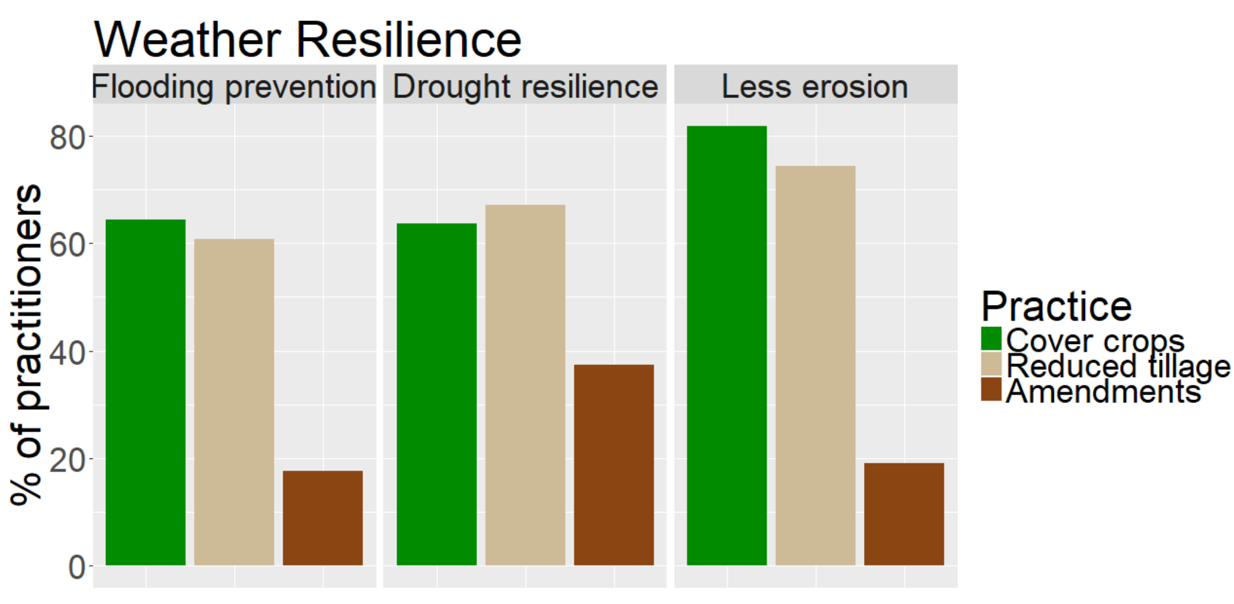


Figure 1: Soil health practices and their impact on resilience to extreme weather events.

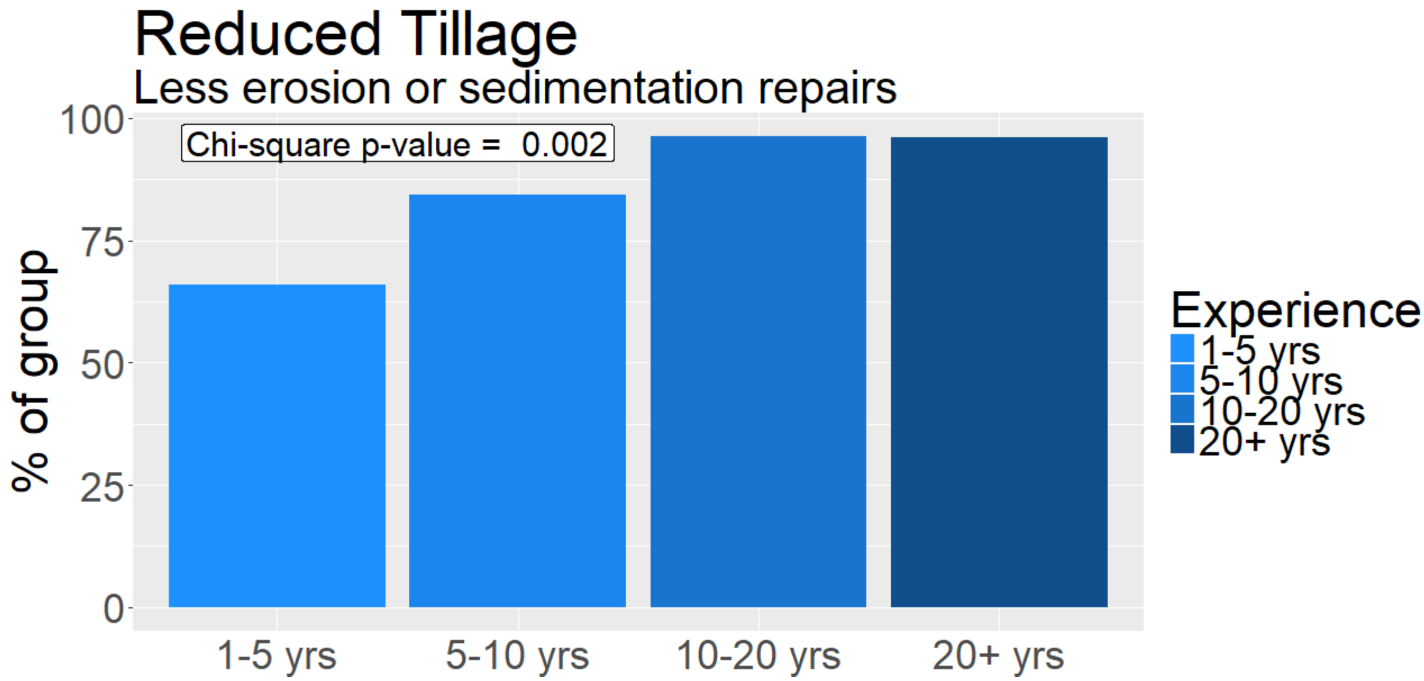


Figure 2: Prevalence of decreased erosion among reduced tillage practitioners at various levels of experience.

Table 1: Reduced Tillage. Ranking of the top three most common financial benefits experienced by farmers who use reduced tillage for all crops (n=125), exclusively corn and soybean production (n=17), and exclusively vegetable production (n=13). The percent of farmers within each group who confirmed a specific benefit is included in parentheses.

Rank	All Crops	Corn & Soybean	Vegetables
1	Less erosion repairs (83.2%)	Less labor, fuel, or equipment (88.2%)	Less erosion repairs (69.2%)
2	Less labor, fuel, or equipment (74.4%)	Less erosion repairs (76.5%)	Greater yields (69.2%)
3	Greater yields (52%)	Greater yields (35.3%)	Less labor, fuel, or equipment (53.8%)

Table 2: Cover Crops. Ranking of the top three most common financial benefits experienced by farmers who use cover crops for all crops (n=149), exclusively corn and soybean production (n=24), and exclusively vegetable production (n=19). The percent of farmers within each group who confirmed a specific benefit is included in parentheses.

Rank	All Crops	Corn & Soybean	Vegetables
1	Less erosion repair (83.9%)	Less erosion repair (95.8%)	Less erosion repair (78.9%)
2	Greater yields of cash crops (50.3%)	Source of animal forage (45.8%)	Greater yields of cash crops (78.9%)
3	Lower fertilizer inputs (47.0%)	Greater yields of cash crops (33.3%)	Lower fertilizer inputs (57.9%)

Contact: cwm77@cornell.edu; website at newyorksoilhealth.org

NEW YORK SOIL HEALTH

Farming in the Lake Champlain Basin

Since 2013, the Lake Champlain Basin Program has supported the activities of a full time agricultural practices specialist, located in the Region 5 NYS DEC office in Ray Brook, NY. This position aids any small farm in the NY portion of the Basin with best management practices that reduce potential non-point nutrient loading to surface waters. Through partnering with private and public agencies, farm hosted field meetings, classroom workshops, and individual farm visits, the positive effects of the Lake Champlain Basin Program agricultural activities are bearing positive results. Small tributaries are our most valuable resources for filtering nutrients effectively. These tributaries foster trees and shade, rocky pools, fish spawning habitat and vegetated floodplains. Excess nutrients flowing into these tributaries can become concentrated into the waters of the Lake, creating excesses that add up to increase harmful cyanobacteria blooms. Agricultural practices in NY contribute approximately 23% of the phosphorus loads found in portions of watersheds touching the NY borders.

Farmers are engaged in many efforts to reduce phosphorus loads through practices such as reduced tillage, restricted fertilization practices in wet weather conditions, and use of technology that provides accurate field data. Field days where new practices are being tested are a great way for farm operators to come together and view what works and what needs tweaking. Through all these efforts, farms are achieving higher levels of resource stewardship to combat nutrient loading of the Lake. Lake Champlain Basin farmers are dependent on healthy soil and water sources to maintain their livelihoods and are enhancing their communities by working to be a part of the solution for a healthy Lake.

The Lake Champlain Basin Program coordinates the implementation of *Opportunities for Action*, a management plan for Lake Champlain. To read the newly released 2018 State of the Lake report, please visit http://sol.lcbp.org.

To find out what your farm can do to help the Lake with its phosphorus diet,
contact: myra.lawyer@dec.ny.gov or call 518-897-1241 and ask for Myra.

Some helpful websites and resource books (only a sampling, there are hundreds more!)

Cornell Reduced Tillage (RT) Project
http://smallfarms.cornell.edu/projects/reduced-tillage/

Organic RT farm stories – A series of organic farm case studies showing how vegetable farmers at many different scales have been successful in implementing reduced tillage practices.
http://smallfarms.cornell.edu/projects/reduced-tillage/farmstories/

Webinar on "Strip till tools and practices" - Lessons learned on managing residue, weeds and insect pests from strip tillage research at Cornell and Michigan State. http://smallfarms.cornell.edu/projects/reduced-tillage/reduced-tillage-webinars/

Video on Zone tillage and short tutorial -

http://smallfarms.cornell.edu/projects/reduced-tillage/strip-tillage/

Small Farm Quarterly (Summer 2017) – Mulch for organic vegetables – grown in place

http://smallfarms.cornell.edu/2017/07/03/mulch-for-organic-vegetables-grown-in-place/

General Resources and Books

Vegetable Farmers and their Sustainable Tillage Practices (Videos) - V. Grubinger 2007

http://articles.extension.org/pages/18437/video:-vegetable-farmers-and-their-sustainable-tillage-practices

Building Soil for Better Crops – SARE

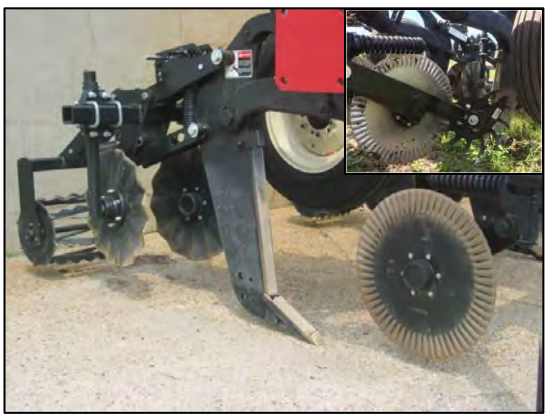
https://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition

Managing Cover Crops Profitably – SARE

https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

Designing zone tillage systems for organic vegetables – Summer 2018

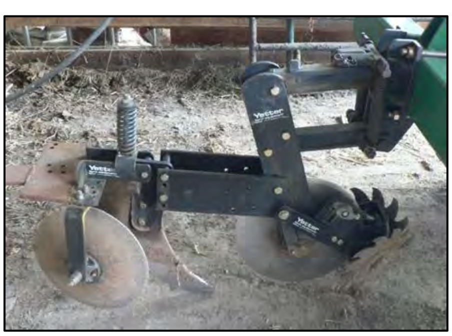
- Zone tillage (ZT) targets disturbance to the planting row and reduces tilled area by at least 50% when compared to conventional tillage.
- In northern climates, ZT can balance some of the soil-improving benefits of no-till with the well-known advantages of tillage: finer seed bed, soil warming and aeration.
- Zone-till needs to be adapted for organic systems to overcome common barriers to reduced tillage - high weed pressure, interference from surface residue, and low soil nitrogen (N) availability.
- Successful farm adoption requires system-level changes: selecting specific crops in a rotation, planning cover crop management, and acquiring and/or modifying tools that work in moderate to high residue conditions.



Stacking tillage tools can save time for field prep and reduce labor and fuel needs. Deep zone tillage rips a narrow channel below compacted zones to break up pans (plow, disc, rototiller) and loosen soil in a ~12" zone to prepare a seedbed, often in one pass. Components can include:
1) coulter for cutting residue
2) row cleaners for raking residue aside
3) deep shank for alleviating compaction in the planting row
4) wavy coulters/discs for filling the slot and building the zone
5) cultipacker wheels/rolling baskets for breaking clods and firming soil.

Equipment combinations can be fit the farm. The tools used and depth of operation will depend on farm-scale, access to equipment, field history and soils. Generally, deep zone units require 4WD and 30-40 HP per shank.

- A Yeoman's plow requires a custom-built finishing unit (or a second pass) but is a lighter unit and shanks can be moved around easily to allow flexibility for different crop spacing.
- Other tools for shallow operation are available or can be constructed.
- At smaller scales, a subsoiler in combination with a walk-behind rototiller in-row is an option.



Winter hardy cover cropping for zone tillage: putting the pieces together to maximize cover crop benefits

Much attention has been given to cover crop-mulching with winter rye grown in-place. Winter rye can be planted in late fall and has high biomass potential for suppressing weeds but it can suck up moisture in a dry spring and tie up soil N for heavy feeding vegetables. The residue can also cause trouble without the appropriate tools, especially as weeds escape. Research on different winter hardy cover crop mixes and mulch management practices provides lessons to share and build upon to support zone-till adoption.

Principle – Cover crops can provide additive benefits (e.g. weed suppression, organic matter, soil cover, active roots) when combined with reduced tillage practices.

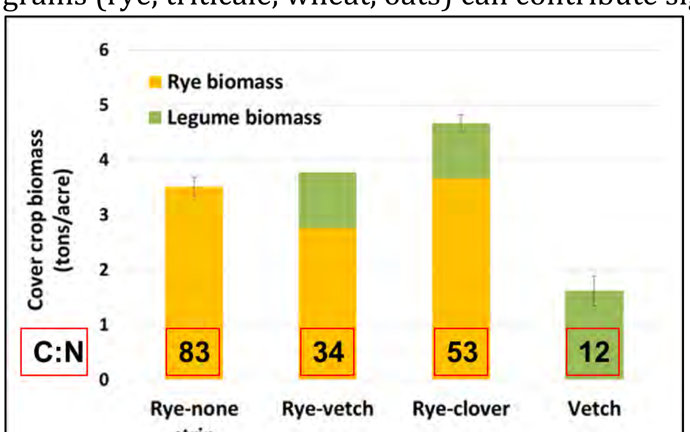
Question - How do we maximize cover crop benefits for zone-till and balance weed, nitrogen, and residue management challenges to be successful?

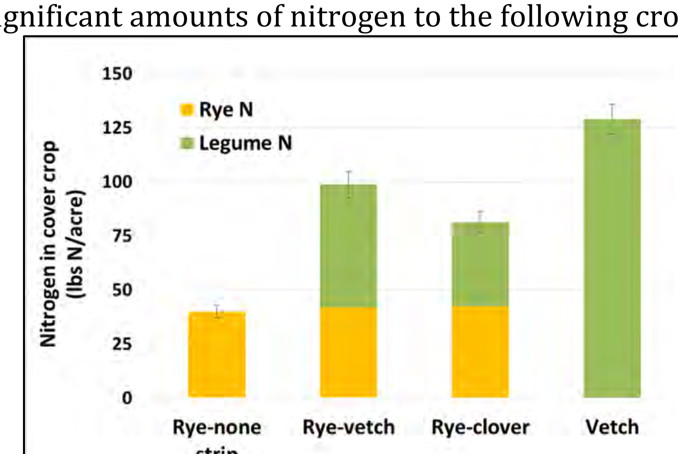
Zone tillage is a system that goes beyond the tillage tool.

Key decision points

- **Late Aug to mid-Sept -> Cover crop selection and planting –** e.g. cover crop species (cereals, cereal + legume mixtures, or legumes), planting date and seeding rate, strip or mixed planting
- **Late May to mid-June -> Cover crop management –** e.g. mowing and leaving in-place as mulch, repeated mowing (2-3x), cover crop removal (cut and carry), tool used for mechanical termination
- **Mid-June to early July –> Tillage and cash crop planting –** e.g. intensity of tillage, row cleaners, planter
- **July to Aug -> Cultivation –** e.g. tool types (high or low residue), timing and frequency

Maximizing cover crop growth in spring provides organic matter and legume-nitrogen available to the crop. Cover crops grown to anthesis can be killed mechanically without tillage. The timing is easier to determine in monocultures (e.g. winter rye or hairy vetch alone) and it's harder to optimize for all species when planted in mixtures. Mowing hairy vetch at full-flower will minimize risk for regrowth and seed production. Legumes (hairy vetch, crimson clover, Austrian winter pea) planted alone or with cereal grains (rye, triticale, wheat, oats) can contribute significant amounts of nitrogen to the following crop.



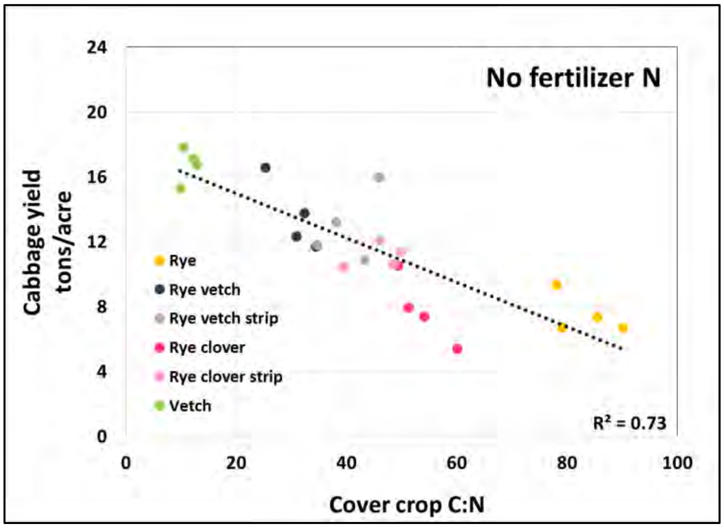


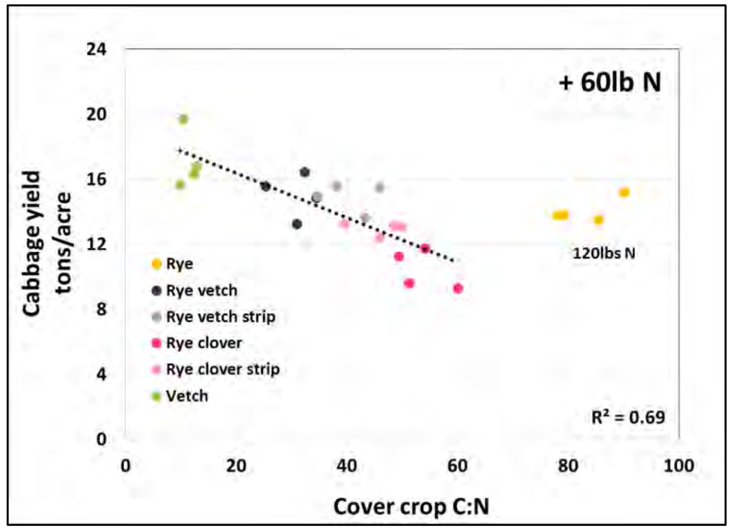
Cover crops and mowing equipment effect residue interference for planting. Row cleaners are very important for building clean planting zones in high residue and work best after flail mowing. Flail mowers finely chop and lay biomass evenly compared to a rotary mower and front or side-mounted units avoid driving over cover crops and give a more complete kill. Belowground rye residue, roots and crowns, can lead to a rougher planting conditions when compared to finer-rooted vetch.

Mowing and row cleaning in winter rye

High-residue cultivation tools are critical for controlling weeds in mulch. Mowed cover crop mulches don't provide season-long weed control (≤ 30 days) but can reduce cultivations (1-2 depending on the year). Rolling cultivator tools, disc and spider gangs, can work despite surface residues and be effective for between-row weeds while finger weeders have shown some success for in-row weed control. Residue from hairy vetch alone breaks down quickly and provides little mulch benefit but can be cultivated with a range of tools.

Crop yields are related to nitrogen availability from the cover crop and not limited by reduced tillage. Brassicas are very responsive to nitrogen. Vetch is a big nitrogen contributor and has led to high yields without added fertilizer in both wet and dry years (Howard loam). Vetch and winter rye –vetch mixes can produce similar or greater yields than winter rye with 120lbs of fertilizer nitrogen. Zone-tilled vetch has produced similar yields to rototilled vetch.





Considerations for trialing zone-till practices on the farm:

- Plan for large seeded vegetable crops (e.g. sweet corn, beans) and/or transplants (e.g. brassicas, cucurbits) because they don't require a fine seed bed.
- Try cucurbits for a single-row zone-till system after winter hardy cover crops. Wider between-row spacing makes for less zones and edge to manage. There is also room to mow cover crops repeatedly during early crop growth if regrowth is a problem.
- When using winter rye or mixtures dominated by cereal grains, follow with low nitrogen demanding crops (e.g. beans). Leaving the strips in the cover crop (blocking off planter) can help reduce residue in the planting row.
- Use cover crop mixtures dominated by legumes and a lower cereal seeding rate for less residue. They are easier to plant into and cultivate without highly specialized tools.
- Try an alternative management with cereal-legume mixes for more biomass with less residue. Mow several times over spring, then subsoil or zonebuild in the planting zone in combination with shallow surface tillage (disc or rototiller).

Find more project resources at **smallfarms.cornell.edu**

IDEAS or QUESTIONS? Contact Ryan Maher, Cornell Small Farms Program, rmm325@cornell.edu.

Work supported by NIFA-USDA OREI 2014-05381, USDA Hatch, and TSF

CORNELL small FARMS PROGRAM

Controlling Weeds in Small-Seeded Crops Using Cultivation

Bryan Brown, NYS IPM Program, Cornell University
Daniel Brainard, Michigan State University
Sam Hitchcock Tilton, Michigan State University
(Adapted from the Proceedings of the 2018 Empire State Producers Expo)

Cultivation may be used to improve weed management in small-seeded crops. It is typically most effective on small weeds in dry, loose soil. Aggressive cultivators used between crop rows can be very effective. However, it remains a challenge to use cultivation to control weeds in the crop row without damaging the crop. In-row cultivation tools rely on a size difference between the weeds and the crop – meaning they are designed to cause just enough soil disturbance to kill small weeds while allowing the larger crop plants to survive. These tools are typically sensitive to working conditions (Fig 1). A new generation of cultivators allow for several different tools to target the in-row zone at once. Such "stacking" of tools has been used to greatly increase the percent weed control in corn (Brown & Gallandt 2018), but few studies have been conducted in small-seeded crops. Therefore in 2017, in-row cultivation tools used singly and in stacked combinations were evaluated in carrot crops in Michigan. Carrots were managed with a pre-emergence flame weeding, a hand weeding at around 40 days after planting, and one or two between-row cultivations. An in-row cultivation was conducted on 1" tall weeds at around 25 days after planting using the tools listed in Table 1. Weeds and crop plants were counted before and after cultivation to determine effectiveness. Overall, the "stacked" tool combinations killed a greater percentage of the weeds, but also killed a greater percentage of the crop. While the finger weeders killed the lowest percentage of the crop, the disc hillers had the highest ratio of weeds killed to crop plants killed (Fig 2). Considering the crop loss, yield was somewhat minimally affected, possibly due to increased size of carrots in plots where density was reduced. The effectiveness of the in-row tools varied greatly with conditions, which suggests that further work is needed to determine the optimal adjustment for different soils, crops, and weeds. The torsion weeders appeared to be the most sensitive to variable conditions while the finger weeders seemed to be the least affected.

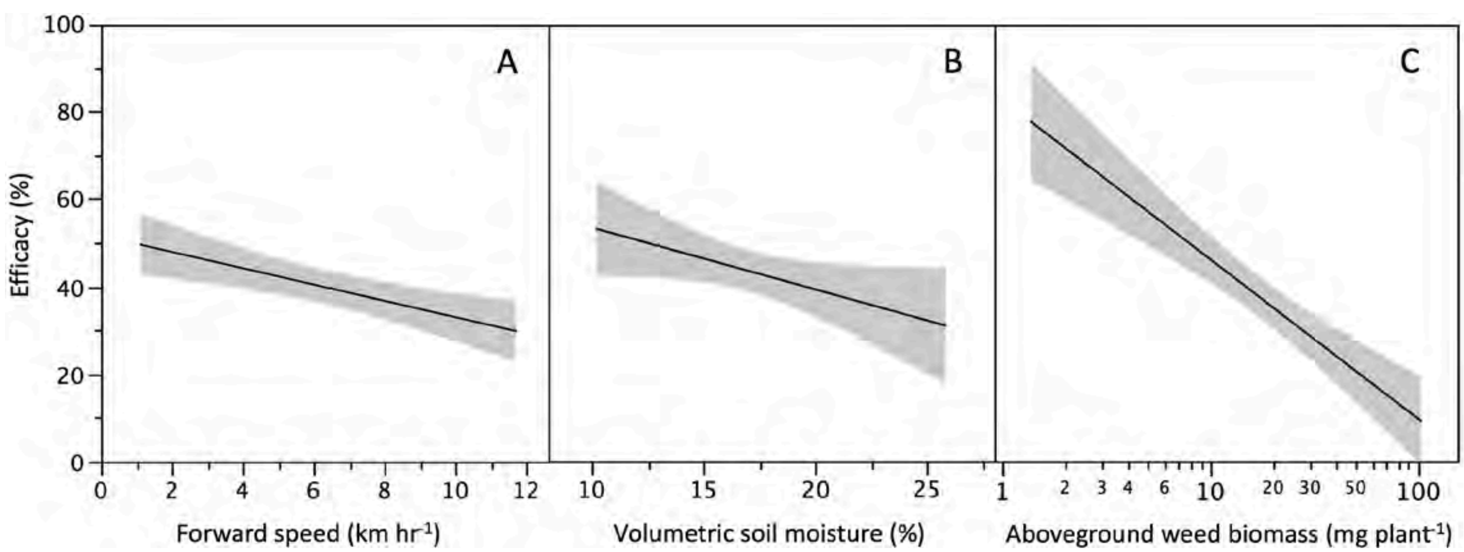


Figure 1. Averaged efficacy (weed control) of torsion, finger, and harrow weeders as tractor forward speed (A), soil moisture (B), and weed size (C) varied. Effectiveness was most strongly affected by weed size. The effect of speed was counter-intuitive and demonstrated that in-row tools need to be set more aggressively when using higher speed. Adapted from Brown & Gallandt (2018).

Table 1. Averaged results of the three in-row cultivation trials in carrots.

In-row cultivation tool	Weeds killed (%)	Crop plants killed (%)	Yield (1,000 lb/ac)
harrow	20	17	26
finger	39	16	25
torsion	46	33	22
disc hillers	57	20	28
finger / disc hillers	79	38	22
finger / harrow	48	32	19
torsion / finger / harrow	55	31	23
none	-30*	0	26

*When no tool was used, 30% more weeds had emerged in the time between counts.

Figure 2. Disc hilling demonstrated potential to bury 1" tall weeds in young carrots but further adjustments may be needed to reduce crop damage. Photo credit: Sam Hitchcock Tilton

References

BROWN B & GALLANDT ER (2018). Evidence of synergy with ‘stacked’ intrarow cultivation tools. Weed Research. https://doi.org/10.1111/wre.12309

Acknowledgements

This work was supported by the USDA National Institute of Food and Agriculture, Organic Agriculture Research and Extension Initiative Competitive Grant, “Farmer designed systems to reduce tillage in organic vegetables.” Accession Number 1004267; A. Rangarajan, Project Director.

WEED SEEDBANK MANAGEMENT USING REDUCED-TILL PRACTICES

Maintaining effective weed control and building soil health are important goals for sustainable organic crop production. Management practices focused on just one of these goals, however, can often inhibit the other. For example, tillage and cultivation are often the primary weed control tools for organic growers, but intense and frequent soil disturbance can lead to declining soil health. Efforts to reduce the intensity and frequency of tillage requires a multi-tactic approach for managing weed seedbanks. Understanding the life-cycle and seed traits of troublesome weeds is the first step towards more effective weed seedbank management.

Important traits of weed seeds. Germination in response to tillage related cues is common in agricultural weeds that have an annual life-cycle. Tillage-related germination cues include a light-flash, temperature or soil moisture fluctuations, release of soil nitrate, or increased aeration. Each weed species, however, is likely to respond to a unique combination of these factors that produces a characteristic germination periodicity, or a period of time during each growing season when germination most commonly occurs. The accompanying fact sheet, "*When do weeds wake up*" provides a nice illustration of the germination periodicity for common agricultural weeds in the Northeast. Weed seed size is also an important characteristic because it provides an indication of the soil depth, or position within the soil profile, that limits germination and establishment. Larger seeded weeds, for example, are more likely to have the necessary reserves to emerge and establish from deeper depths in the soil. The Northeastern SARE publication, "*Crop Rotation on Organic Farms: A planning manual*", contains a nice compendium (Appendix 4) from Dr. Charles Mohler that provides characteristics of common Northeastern agricultural weed life cycles and seed traits. This resource may prove valuable for managing weed seedbanks on your farm (https://www.sare.org/Learning-Center/Books/Crop-Rotation-on-Organic-Farms).

Manipulating weed seedbanks. There are several strategies that organic growers can employ to reduce the size of weed seedbanks before or after a given cash crop growing season. We will discuss:

Stale or False Seedbeds. This approach takes advantage of tillage-based germination cues by preparing a seedbed for the cash crop and then delaying planting to allow for a flush of weeds. In organic production, a stale seedbed approach would use flaming to kill germinated weeds prior to planting, whereas a false seedbed approach may employ multiple cultivations on weekly intervals prior to planting. In both cases, limiting the intensity of soil disturbance after the initial seedbed will prevent additional weed germination cues.

High residue mulch. Terminating mature cover crops with a roller crimper to create a surface mulch has the potential to provide high levels of weed suppression and facilitate no-till planting cash crops. Prevention of tillage-related germination cues is one of the primary mechanisms that facilitate this practice. To date, no-till production of organic vegetable remains challenging due to other pest-, soil- and horticultural- tradeoffs.

Crop Sequencing. Crop rotation diversity is perhaps the best strategy for managing weed seedbanks. In organic field crops, rotation to perennial forages or winter grains can promote significant weed seedbank decline. These strategies may also be valuable in vegetable rotations, but highly diversified organic vegetable farms also have the flexibility to strategically alternate early- and late-season crops to manage weed seedbanks.

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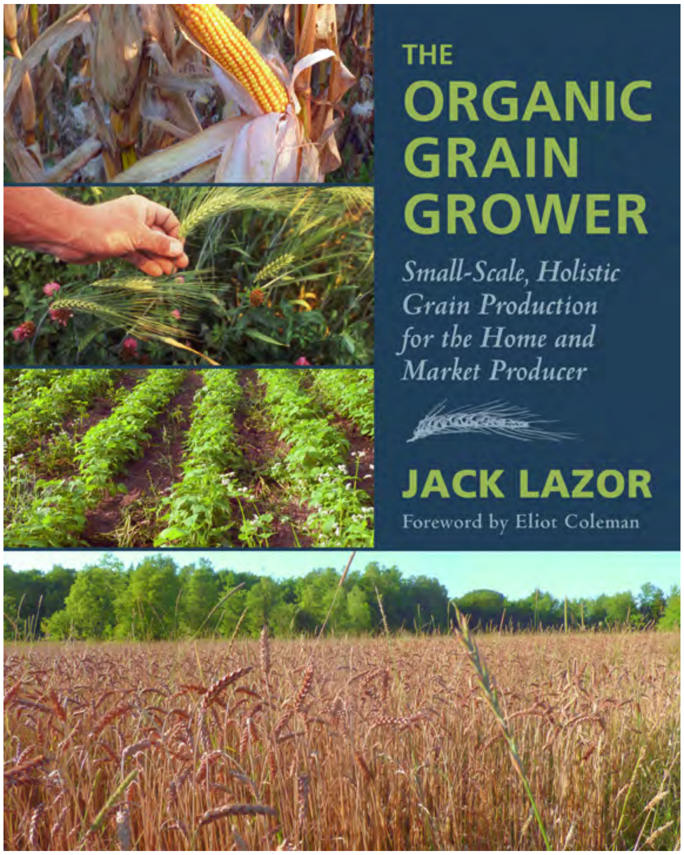
College of Agriculture and Life Sciences



For ordering and product information, please email us at the farm:
orders@butterworksfarm.com

To reach Jack or Anne: jack@butterworksfarm.com

The farm is located in Northern Vermont
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Profile from the Field

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Evaluating the Roller-Crimper for Cover Crops in Corn and Soybean Terraced Ground

Project Title: Evaluating the Roller-Crimper for Cover Crops in Corn and Soybean Terraced Ground
Coordinator: Michael Willis

Location: King City, Missouri
SARE Grant: $4,000
Duration: 2013-2014

To read the full project report, go to www.sare.org/projects and search for project number FNC13-940

Cover crops have helped to improve erosion problems, soil health, and yeilds on Michael Willis' terraced farm in northwest Missouri. Photo by Michael Willis.

In northwest Missouri, a practice known as terracing is used to prevent ditches. Michael Willis, a beginning farmer in northwest Missouri, says that cover crops can reduce the need for terraces, but terraces still prove to be important to prevent ditch formation during the transitional phase from traditional no-till to no-till with cover crops.

Willis owns and farms 64 acres, farms another 1000 acres of row crops with his parents and brother, and helps run his family's 120-head cattle herd.

He had information about the Rodale Institute's cover crop roller-crimper, but Willis wanted to know how effective it could be on irregular or terraced areas. In 2013, Willis received an NCR-SARE Farmer Rancher grant to evaluate the effectiveness of the Rodale roller-crimper on hilly, terraced, and irregularly shaped fields. With a 15.5' wide roller-crimper hooked onto a LaForge front-mounted three-point hitch and 25 acres, Wills commenced his experiment.

Willis' Key Findings for Rolling-Crimping on Terraced or Irregularly-Shaped Fields

- The roller-crimper was able to handle gentle curves, but if it looked like a curve would be too sharp, it was best to be safe and treat it like a corner. Turning too sharply bent the arms of the front-mounted three-point hitch, though they sprung back into place once the roller-crimper was lifted. However, doing this too frequently could break them or leave them permanently bent.

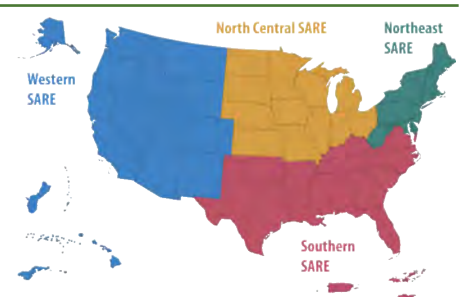
- Irregularly shaped fields could be planted while rolling and crimping, but sharper curves needed to be treated like corners. Wide grass borders around the field could make these areas easier to maneuver around, giving ample room to turn around for another pass.

- Rolling and crimping while planting on terraces was easiest on straight terraces. Cover crops near the terrace riser were harder to reach due to the concern of hitting the riser with the roller-crimper.

- Cover crop mixes made rolling and crimping more difficult. When certain species of cover crops were ready to crimp, others still needed time to mature. Having a pure stand of one cover crop made it much easier to manage. Planting soybeans into cereal rye was the easiest to manage.

- The roller-crimper did a better job controlling cereal rye that had higher fertility. Rye in lower fertility areas was shorter and had tougher stems, causing them to spring back up after the roller-crimper rolled over the rye. However, Willis was able to do his pre-emergence application of herbicides even in less-than-ideal field conditions because of the large amount of cover crop biomass—the sprayer didn't cut ruts in the field or pick up much mud on the tires.

Willis has noticed improvements in soil structure since he started using cover crops. He took a soil active carbon test in 2013 on a field where he planted soybeans into rolled and crimped cereal rye, and it tested .79 grams of active carbon per kilogram of soil. He took a test from the same area in 2014 and it tested .82 grams of active carbon per kilogram of soil.



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Six Things Your Mother Never Warned You About When Using Roller Crimpers

Troubleshooting Guide: Tips Tricks & Traps to Avoid Roller Crimper Failures

Jack Rabin, 2013
Supported in part by NESARE

Problem 1: Uneven cover crop termination after crimping

- When pulling a rear 3-point hitch mounted roller crimper, the tractor tires push cover crops down prior to contact with the blades, resulting in uneven crimping in the wheel tracks. Cover crops rebound in a few days, interfering with planting and weed suppression. While front mounting is recommended, a Laforge Systems (or equal) front 3-point hitch may cost more than a roller crimper; more than small farmers or trial users want to spend.

- Uneven fields from rocks, tire ruts, rough seedbed preparation previous fall or hard dry surfaces from low May soil moisture cause blades to bounce over uneven soil contact, even with the cylinder is weighted with water. Cover crops rebound and continue growing instead of dying and desiccating.

Solutions: Prepare a smooth fall seedbed, crimp with remaining soil moisture, drive in reverse if rear-mounted, and use burndown herbicide

- Prepare smooth cover crop seedbeds the previous fall. Avoid creating ruts or "mudding out" crops in the fall on fields destined for rolling next spring.
- The soil surface needs to be firm enough to deliver an effective crimping force against the soil surface. Crimp with sufficient residual spring soil moisture, but not when fields are wet enough to cause compaction. (Designs using weighted gangs of smaller rollers to track uneven field surfaces used in Latin America may become available in the future according to Sjoerd Duiker at Penn State.)
- Combine crimping with non-selective burndown herbicide at termination.
- If rear-mounted, driving in reverse results in even termination. Avoid operator neck strain. If driving in forward, the operator can stagger wheel tracks and make multiple passes. Because cover crops must be rolled in one direction parallel to planting, travel time, fuel consumption, compaction and labor will increase.

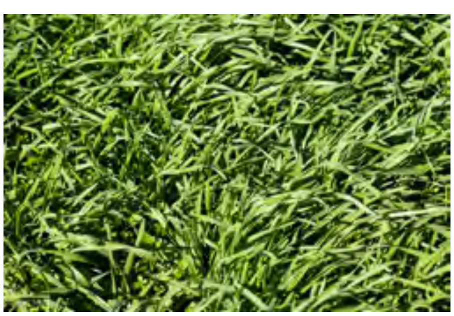
RUTGERS
New Jersey Agricultural
Experiment Station

Problem 2: Unacceptable weed pressure penetrates mat, no rescue control options

- Long season crops can be lost to poor weed suppression, especially competitive summer annuals like Jimson weed, ragweed, morning glory, hairy Galinsoga, pigweed and grasses.

Solutions: Seed cereal rye cover crop at 2-2½ bu/a in early Sept, spot treat herbicides

- Seed at high rates early in the fall. Treat the cover crop like a cash crop by growing the largest biomass and terminating it at the best time.
- Trials indicate seeding rye at rates above 2½ to 3 bu/a do not increase biomass, but do increase weed suppression. About 5,000 lb. of above ground cover crop residue is the minimum required to suppress weeds. The USDA-ARS Beltsville suggests 7,000 - 8,000 lb/a residue, higher as you move geographically south.



Dense rye cover crop stand at 33 days after seeding 2½ bu/a

Ragweed penetrating insufficient rolled cover crop residue seeded 1 bu/a

In roller crimper no-till tomato, smooth pigweed and ivyleaf morning glory penetrated a thick rye mat, requiring additional 41-hr/a hand weeding.

- Avoid wheat; wheat straw residues are less durable and decompose more quickly than rye.
- Prevent winter cover crop damage from wildlife like geese or deer.
- Top dress in March with 30-40 lb/a N fertilizer.
- Use non-selective burndown herbicides, Glyphoaste or Gramoxone shielded at max 30 psi plus nonionic surfactant. Labeled selective post-emergence grass herbicides can be used.
- Success with OMRI approved organic non-selective herbicide treatments depends on controlling weeds when they are very small (< 4 leaves) with high spray coverage (70-100 gal/a water). There are no OMRI approved products that aid terminating mature rye (Personal Comm., Bill Curran, Penn State). The following organic herbicides do not translocate, less effective for desiccation, and expensive when applied at sufficient coverage:

  Acetic acid (vinegar) concentrated solutions > 15%
  Ammonia fatty acids (Pelargonic acid, Scythe is not OMRI approved)
  Citric acids (24%) + clove oil (8%), e.g., BurnOut II
  Clove oil concentrates, e.g., Matratec, Matran
  d-Limonene citrus oil solutions, e.g., Avenger AG or GreenMatch EX
  d-Limonene + castor oil, e.g., GreenMatch

Problem 3: Ideal May termination dates delay planting early crops

- Early cover crop termination does not yield sufficient residue to suppress weeds. It is a weakness of roller crimpers that termination conflicts with early planting. There is additional delay after crimping to allow desiccation before planting.
- Results from S. Mirsky at USDA-ARS indicates the ideal time to roller crimp cereal rye is when it reaches ~50 to 75 percent flowering (anthers visible throughout the heads). Ted Kornecki of USDA waits until the 'early milk' or 'soft dough' stages of grain head fill to provide the maximum rye residue and ease of rolling. At this stage, rye attains its highest durable straw residue and crimping consistently kills the cover crop before viable seed are produced. Findings were consistent for multiple rye varieties, and ideal maturity stage for rolling did not change based on when in the fall rye was seeded or when in the spring it was rolled.

Solutions: Do not use a roller crimper if making money depends on early maturity

- Do not use no-till if marketing the crop depends on early planting and early maturity. Roller crimper no-till is for main season crops. Candidates include main season corn and soybean, main season sweet corn, pumpkin, winter squash, and late tomato, where the rolled mat reduces fruit contact with soil.
- Speed termination with a burndown herbicide application

Problem 4: Rolled cover sufficiently dense to suppress weeds fouls no-till planters

- Plug transplanter opener shoes can bind when pulled through cover crop mats, especially multi-row gangs on toolbars, resulting in repeated down time.
- No-till seeding or mechanical transplanting vegetables like pumpkin, squash, or tomato through cover crop residue opens a band of soil exposed to weed emergence.

Lodged rye did not roller crimp parallel

Solutions: Desiccate cover crop, hand plant, adjust planter and use large transplants

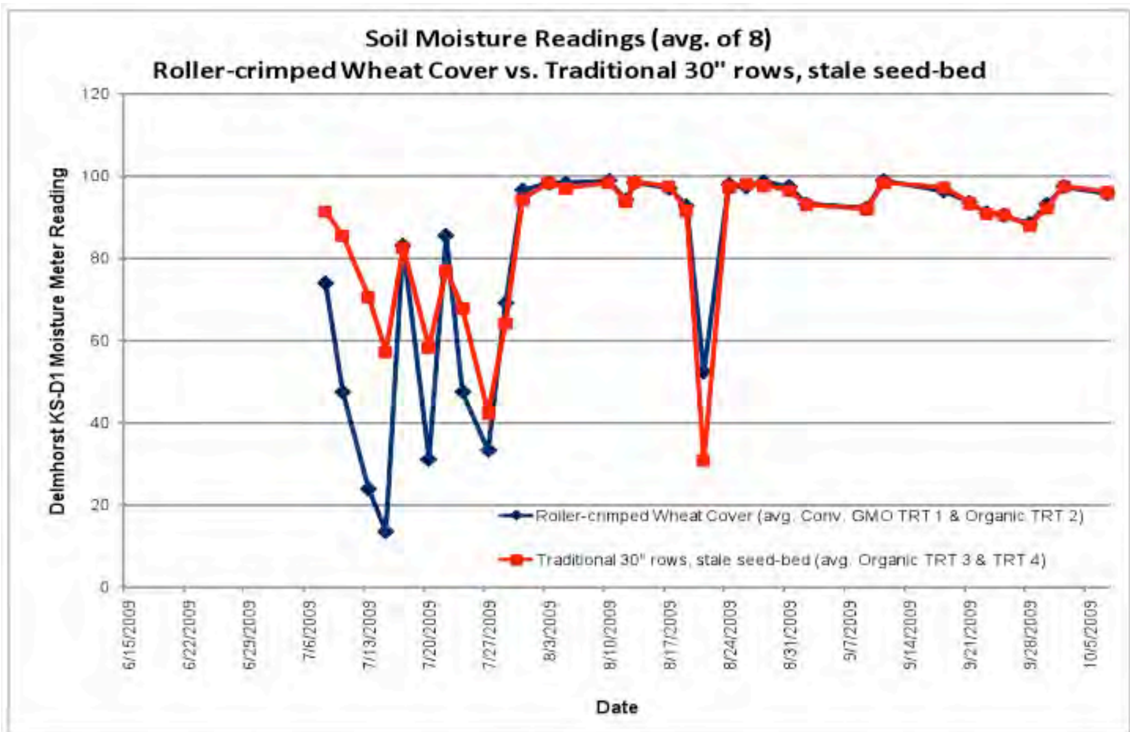
- Roll cover crop in parallel swaths before lodging to minimize binding at planting.
- Delay planting 1-2 weeks or use burndown herbicide at termination to desiccate cover crops.
- Hand transplant or seed smaller fields.
- Plug planters can be adapted to direct seeding pumpkin or squash by dropping seeds through the carousel cups into opened furrow. RJ Equipment of Ontario and Mechanical Transplanter of MI manufacture no-till carousel plug planters.
- With careful adjustment, large sharp coulter blades, and double opener coulters in front of the shoe planters will successfully move through cover crop mats.

Problem 5: Temporary moisture competition from the terminated cover crop

- Planting a crop immediately into crimped green residues, recommended by some advisors, is less successful. In dry seasons, reduced early root zone soil moisture competes with establishment. Later in summer, the mat has an opposite effect; conserving root zone soil moisture.
-Two to three weeks between termination and planting may be needed to eliminate soil moisture competition during critical stand establishment. The chart below shows evapo-transpiration soil moisture loss continued for three weeks in a NJ soybean field (2009) planted into terminated wheat cover crop (blue line) compared to bare soil (red line).

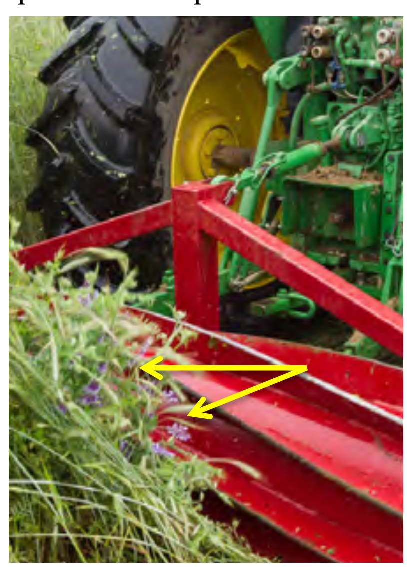
Solutions: Delay planting, drip irrigate transplants, apply burndown herbicide

- Use a broadcast burndown herbicide application just before or after rolling to hasten quickly desiccation of terminated cover crops. The seeding delay waiting for desiccation can be reduced from 2-3 weeks to 1 week.
- Irrigate newly seeded crops when necessary.



Problem 6: Escaped vetch becomes volunteer weed from rye-vetch seed mixtures

- Rye-vetch cover crop mixtures are an established practice to improve soil and nitrogen fertility. Crimping doesn't reliably kill vetch and date may conflict with viable seed production. Most regions report vetch matures about two weeks after rye, and does not set seed when rye is terminated at 50-75% flowering. This should avoid problems with vetch seedlings becoming weeds and competing with current and future crops.



Solutions: Adjust for vetch in seed mixtures, use burndown herbicide

- It is better to deal with volunteer rye than vetch. Set the rolling date based on vetch maturity instead of rye, or roll twice about two weeks apart.
- Since vetch will regrow if terminated early with rye, substitute later maturing triticale for rye as it has a similar maturity to vetch and can be terminated at the same time.
- Spot treat vetch that escaped termination or apply burndown herbicide before or after rolling to kill vetch.
- Don't use vetch cover crops on fields destined for rolling.

VIRGINIA RESOURCE CONSERVATION & DEVELOPMENT COUNCILS

USDA NRCS

Virginia Cooperative Extension

INTRODUCTION TO COVER CROP ROLLING & THE VA-USDA CRIMPER ROLLER DEMONSTRATION PROJECT

September 2006 Long Version - available at: http://www.va.nrcs.usda.gov/technical/crop_agronomy.html

1. Overview of VA Roller Demo Project

The goal of the Virginia-USDA Cover Crop Crimper Roller Demonstration Project is to evaluate the potential for increased use of cover crop rolling in Virginia. Our strategy is to provide two farm-scale cover crop crimper rollers for Virginia farmers and their advisors to try. Rollers and trailers to move them are available to borrow and use free-of-charge. Rollers are housed in Harrisonburg and Tappahannock. Scheduling is handled by the Soil & Water Conservation Districts in these localities. Read on or call the contacts below to learn more about rolling or borrowing our rollers.

Rolling down rye with our 15.5-foot unit in New Kent County

2. What Is Cover Crop Rolling?

Cover crop rolling is an advanced no-till technique. It involves flattening a high-biomass cover crop to produce a thick, uniform mat of mulch. A cash crop is then no-tilled into the mulch. If the right kind of roller is used on the right cover crop at the right time, the rolling process itself will kill or partially kill the cover crop. This means burndown herbicides can be reduced or eliminated. Other potential advantages and disadvantages of cover crop rolling are listed later in this document.

Cover crop rolling has been used for decades on millions of cropland acres in South America. It has also been used successfully by individual farmers and researchers from Alabama to Pennsylvania, but has yet to see widespread adoption in the U.S.

Our 10.5-foot roller at work in Shenandoah Valley

Contacts for VA-USDA Roller Demonstration Project

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Keith Balderson, VA Cooperative Extension
(804) 443-3551 or *thbalder@vt.edu*

Organic soybeans no-tilled into rolled rye, King & Queen Co.
No-herbicide no-till!

Pumpkins no-tilled into rolled rye, New Kent Co.

Our special trailers can lay flat on the ground if needed, so rollers can be loaded and unloaded without lifting.

3. Who Should Consider Rolling?

Cover crop rolling is ***not*** for everyone. To help you decide if it might work for you, we've provided the following profiles of Virginia growers who we think are most likely to benefit:

A. Traditional Field Crop Producers

If you are a traditional field crop producer (corn, soybeans, cotton, etc.), cover crop rolling may be for you if most or all of the following are true:

1. You are an experienced no-tiller or you plan to become one;
2. You grow later-planted crops such as full-season soybeans or cotton, or you might consider delaying the seeding of earlier-planted crops like corn;
3. You grow cover crops, you are willing to kill them late, and you are willing to manage them for high biomass production;
4. You have a strong interest in maximizing soil organic matter and soil quality on your land.

B. Vegetable and Specialty Crop Producers

Many vegetable and specialty crop producers should take a close look at cover crop rolling, whether or not they have ever no-tilled a crop before. For example, there is a special place for rolling ahead of crops like no-till pumpkins because of the clear production advantages of keeping fruit from touching soil all summer.

C. Organic Producers

Cover crop rolling should be of great interest to all organic (pesticide-free) producers, because it is opens the door to herbicide-free no-till and the cost-savings and soil quality benefits associated with reduced soil disturbance.

4. Which Cover Crops Roll Best?

A. Many Species

Rolling is for killing annual cover crops. It is most often used on winter annual cereal cover crops like rye. In Virginia, tall cereal rye appears to be much better suited to rolling than barley and wheat. This is logical because most barley and wheat has been bred for standability and short straw. Winter annual grass/legume mixes like rye/hairy vetch or barley/crimson clover also work well.

B. High Yields

Rolling is for killing high-yield cover crops. Even if the right species is rolled with the right tool at the right growth stage, the full benefit of rolling will not be seen unless there is a lot of cover crop biomass. Therefore, you may need to spend more time and money growing a cover crop for rolling than you would growing a typical cover crop. For example, if you are trying to grow a high-biomass rye cover crop for rolling on a sandy Virginia Coastal Plain soil with low nitrogen (N) carryover from the previous crop, a minimum spring application of 30 lb/ac of N will probably be needed to achieve the desired biomass. Remember, we expect this investment in your soil to pay you dividends in the long run, as further discussed below.

C. Uniform Stands

Rolling is for killing uniform stands of high-biomass cover crops. Uniform stands are important for uniform mulch thickness, which can have key planting and weed control implications.

5. Which Cash Crops Work Best with Rolling?

Cover crop rolling can be and has been used successfully ahead of almost any crop that can be no-tilled, either by direct-seeding or no-till transplanting. However, rolling fits best ahead of later-planted cash crops in Virginia such as full-season soybeans, cotton, and vegetables.

6. Short-Term Advantages of Rolling

1. Maximum cover crop biomass:
   Rolling works best when a cover crop is killed late and when it is managed for high biomass. Therefore, the practice is associated with maximizing the amount of above- and below-ground organic matter returned to the soil by a cover crop. If the cover crop includes a legume, N carryover to the next crop will be also maximized.
2. Burndown herbicide reduction:
   When done properly, rolling can allow for reduction or elimination of burndown herbicides (see Page 5).
3. Drying out soil profile ahead of cash crop planting:
   Heavy water use by a cover crop can dry out the soil ahead of cash crop planting. On certain soils in certain years, this can be a production advantage.
4. Positive mulch effects:
   The following benefits can be expected when a cash crop is no-tilled into a thick, uniform mat of mulch:
   a. Better weed control, especially early in growing season;
   b. Cooler soil and improved moisture retention in mid-summer;
   c. Maximum soil protection from raindrop impact and erosion;
   d. Better environment for some beneficial insects and organisms such as earthworms;
   e. No bare soil for cleaner picking and products (e.g. pumpkins).

7. Short-Term Disadvantages of Rolling

1. Higher cover crop production costs:
   To maximize the advantages of rolling, cover crop biomass should be maximized. This usually requires more management (timely seeding, etc.) and inputs (more seed, better seed, fertilization, etc.) than most farmers typically devote to cover crops.
2. Late cover crop kill date
   Some examples of disadvantages of killing a cover crop late include:
   a. Delayed cash crop planting date;
   b. Risk of the cover crop setting and dropping viable seed.
3. Drying out soil profile ahead of cash crop planting:
   Heavy water use by a cover crop can dry out the soil ahead of cash crop planting. On certain soils in certain years, this can be a clear disadvantage.
4. Negative mulch effects:
   Some possible disadvantages of no-tilling into a very thick mat of mulch:
   a. Problems getting seed-to-soil contact;
   b. Slower soil warming, germination, and seedling growth in a cool spring;
   c. Better environment for some pests organisms such as slugs, cutworms, etc.;
   d. Possible early-season N tie-ups and deficiencies when a grass cash crop like corn is no-tilled into a mulch of very mature, high C:N ratio grass cover like rye.

Straight-bar crimper roller: a bumpy ride at 6+ mph!

Early boot-stage rye.
Good biomass but TOO EARLY to roll.
(11 April 2006, New Kent Co., VA)

Rye at pollination stage. Great biomass and ready to roll.
Note same shovel as in picture above.
(10 May 2005, Rockingham Co., VA)

Rye at grain-fill stage, perfect for herbicide-free rolling. Think there's enough biomass here?
(3 May 2005, Southampton Co., VA)

8. Long-Term Considerations

When evaluated on a single-year basis (in the absence of cost share), the economics of growing a cover crop are often break-even or worse. But when cover crops are consistently grown over a period of years, their cumulative soil organic matter and nutrient cycling benefits are much more likely to translate into increased profit. This is especially true if cover cropping is used in conjunction with continuous no-till and crop rotation. The many positive interactions between cover cropping, continuous no-till, and crop rotation can't be overemphasized. We are starting to understand that combining these practices over a period of five to 10 years offers a real opportunity to improve long-term profitability for Virginia farmers. This is in part due to no-till fuel and time savings and in part due to production efficiencies that accumulate as soil quality improves. Adopting these practices also means major environmental and conservation benefits.

Where does rolling fit in? Managing cover crops for high biomass production simply accelerates the long-term process of soil quality improvement described above. Once a farmer decides he wants to speed up the soil organic matter buildup that occurs with continuous no-till, then high biomass cover crops make sense. And once a farmer decides that he wants to grow high biomass cover crops, then rolling makes sense. This is why rolling is expected to have significant appeal among farmers who are committed to no-till and to increasing their soil organic matter levels and soil quality.

9. Crimping vs. Rolling

Crimping involves rolling down a cover crop with a special tool that not only flattens the crop, but also repeatedly crushes (but does not cut) cover crop stems. On our machines, the blunt edges of three-inch tall metal bars welded to the roller drum do the crimping (see picture on next page). Crimping further damages the cover crop and increases the likelihood it will stay down and die after rolling. Therefore, using a crimper becomes more important if you are trying to kill a cover crop with no herbicide.

If a standing cover crop is killed with a full rate of herbicide, then almost any device (roller without crimping bars, cultipacker, etc.) can be used to roll down the crop. Some farmers say they are able to cut herbicide rates on flattended mature cover crops even when a specially-designed crimper has not been used. But if your goal is to minimize or eliminate burndown herbicides, you should try a specially-designed crimper roller such as one of our demonstration units.

Curved crimping bars on our rollers make for a smooth ride.

10. Features of Our VA-USDA Crimper Rollers

Our two demonstration cover crop crimper rollers were custom built in Dayton, VA. Their design is based in large part on published specifications for a smooth rolling cover crop crimper roller developed by the USDA Agricultural Research Service (ARS) Soil Dynamics Lab in Auburn, AL. Their most important features are:

1. Maximum crimping action:
   Our rollers are built heavy to maximize crimping and minimize need for burndown herbicides. They can also be filled with water for added weight.
2. Smooth rolling action:
   Our crimping bars are curved around the roller cylinder in order to eliminate the excessive vibration that occurs at high operating speed with a traditional straight crimping bar design.

11. When Should I Roll?

Timing of cover crop rolling is a key issue. There are many general principles and tradeoffs for you to consider. As our understanding of rolling improves, we will update the guidelines offered below:

A. Timing: General

1. There is typically very little value in crimping/rolling annual cover crops until they have started the reproductive phase of their life cycle (bloom stage);
2. The more mature the cover crop is when it is crimped/rolled, the less supplemental burndown herbicide will be needed;
3. If you allow the cover crop to mature too much before crimping, it will produce and drop viable seed. Depending on your system, this may be a very important reason not to wait too long before crimping;
4. Our recommendation is to roll a few weeks prior to cash crop seeding, but some growers roll immediately before or even after no-tilling their cash crop;
5. If you crimp/roll with reduced or no burndown herbicide, it seems wise to allow some time to see if your cover crop dies before no-tilling your cash crop. The exception to this is if you have the option of cleaning up cover crop regrowth with selective herbicides once the cash crop is growing;
6. When rolling is used in conjunction with systemic (Roundup-type) herbicides, spraying has been successfully done before, during, and after rolling;
7. In 100% herbicide-free systems, be prepared to make additional passes with roller or flail mower in case the first crimping does not fully kill the cover crop.

B. Timing: Winter Cereal Cover Crops

Here are additional suggestions for rolling winter cereal cover crops with our VA-USDA crimper rollers. It may be possible to cut herbicide rates even lower than described below, but we'll need to evaluate results of on-farm tests before we can say more.

1. Do not consider rolling cereals with our units unless seedheads are visible across the entire field;
2. If a high-biomass cereal crop is crimped with our units around the time of flowering/pollination, it will likely stay flat and die if burndown herbicides are reduced (¾ to ¼ of normal rates). Be ready to get covered in pollen if you roll at flowering.
3. If a high-biomass cereal crop is crimped with our units during the grain fill period, it will likely stay flat and die even if burndown herbicides are significantly reduced or eliminated (½ of normal rates to no herbicide). If carryover of viable cover crop seed is a problem for you, do not wait until later grain fill stages to roll.
4. If you delay crimping with our units until the soft dough stage, it is very likely the crop will stay flat and die without the use of herbicides.

Here the planter "hairpinned" rolled residue into the planting slot and the seed never touched soil. Sharpen your coulters!

12. How Should I Roll?

More advice for maximizing success with our rollers:

1. Match roller and planter width:
   Many growers say that the best option is to roll down the cover crop in the same direction/pattern as you expect to plant the cash crop. For this reason, a roller width that exactly matches the width of your no-till planter or drill is best.
2. Run parallel:
   If roller and planter widths don't match up, many growers find they are able to still plant effectively as long as their cash crop rows run more or less parallel to the direction of rolling. Some prefer to plant at a slight angle with respect to the direction of rolling. In both cases, no-till seed furrow openers and other ground- or residue-engaging hardware on the planting machine are typically moving aside most of the heavy residue rather than cutting through it.
3. Don't run perpendicular (unless your planter is up to the task!):
   Most growers agree that planting perpendicular to the direction of rolling is not a good idea. This requires cutting through large quantities of residue and increases the likelihood of hairpinning, poor seed-to-soil contact, and bad stands.
4. Look out for lodging:
   A real problem occurs when a high biomass grass cover crop like rye lodges or falls over on its own in a random pattern. The result is a "weave" of mulch giving you no clear direction to plant in and variable amounts of residue to cut through as you move through the field. For this reason, minimize the risk of lodging by not over-fertilizing rye or other susceptible cover crops with N. If you are concerned that a crop may lodge before the right stage for rolling, consider rolling early to establish a pattern, even though you expect it to stand back up. Then terminate the crop with another pass at the right time.
5. Crimp, don't cut:
   Remember: the goal is to crush but not cut cover crop stems. Cut plants often regrow. If one of our crimpers is doing a lot of cutting, then most likely the crop is too immature/not stemmy enough or there is not enough total biomass.
6. Manage for high biomass, uniform cover crops!
   A high biomass, uniform cover crop not only makes a better mulch mat — it is also much more likely to stay down and die when rolled! For this reason, we recommend that you seed, fertilize, and otherwise manage your cover crop for maximum biomass and uniformity much as you would a cash crop.

13. Suggestions For On-Farm Tests With Our Rollers

1. We encourage farmers to try with our rollers on limited acreage. This is new technology and disasters can happen.
2. We encourage farmers to use our rollers to set up simple strip or split-field test plots rather than to roll down entire fields in a uniform manner. Both approaches are acceptable, but we will all probably learn more from side-by-side comparisons than from rolling entire fields.
3. On-farm tests need not be complicated. They can be as simple as splitting a field or rolling down one strip in a field and then taking a little extra time to keep track of crop progress. Hard data and yield measurements are ideal, but farmer observations alone are extremely valuable to us. For help with setting up or monitoring on-farm cover crop rolling tests, call the contacts listed on Page 1.
4. Some examples of good side-by-side comparisons:
   a. Cover crop sprayed early vs. rolled down late;
   b. Cover crop harvested for hay or silage vs. rolled down late;
   c. Cover crop rolled down at different growth stages with the same amount of herbicide used;
   d. Cover crop rolled down at the same growth stage with different amounts of herbicide used.

   In all of the above plots, the cash crop could be no-tilled into both treatments on the same day and managed the same way throughout the season.

14. VA –USDA Roller Project Partners

Thanks to all of the following organizations for making this project possible:

1. Northern Neck Soil & Water Conservation District
2. Shenandoah Resource Conservation & Development (RC&D) Council
3. Shenandoah Valley Soil & Water Conservation District
4. Three Rivers Soil & Water Conservation District
5. Tidewater Resource Conservation & Development (RC&D) Council
6. USDA Natural Resources Conservation Service
7. Virginia Cooperative Extension

Cover Crop Rollers for Northeastern Grain Production

In the last several years, farmers in the northeast and other regions of the US have shown interest in using cover crop rollers for high residue conservation tillage.

ARTICLES

Background

Cover crop rollers have been used for decades in Brazil, Argentina, and Paraguay to successfully manage cover crops and their residues (Derpsch et al. 1991; Ashford and Reeves, 2003). Farmers adopted these tools to manage large amounts of cover crop residue for more successful cash crop establishment in no-till systems. This "high-residue conservation tillage" system involves producing large amounts of cover crop residue and using it to suppress weeds, protect the soil from erosion, and conserve soil moisture. In the last several years, farmers in the northeast and other regions of the US have shown interest in using cover crop rollers for high residue conservation tillage. Much of the interest in the Northeast comes from organic grain and vegetable farmers who would like to reduce frequency or intensity of tillage in their rotation.

Description and Potential Use

Cover crop rollers have come in various designs, but are generally made from a hollow steel drum or cylinder 1 to 2 feet in diameter. The roller/crimpers used today generally have blunt blades or knives arranged on the cylinder that crimp or crush the stems of the living cover crop, which then kills it. Rollers flatten and crimp susceptible cover crops leaving an intact mat of soil protective mulch oriented in the direction of planting. This unidirectional mulch can help facilitate planting and improve seed to soil contract and ultimately cash crop emergence.

In contrast to mowing the cover crop, there is less risk of cover crop regrowth when it is rolled, the intact residue decomposes slower, and weed suppression is better from the uniform surface residue.

Several designs have been tested (long-straight blades vs. curved blades vs. other designs) for cover crop control and vibration reduction (Kornecki et al. 2006; Raper et al. 2004). A common design used today has metal blades welded onto a cylinder in a chevron pattern that allows for smooth operation (Ashford and Reeves, 2003). This design was further refined by The Rodale Institute and is now manufactured and sold by I & J Manufacturing of Gap, PA.

Cover crop rollers vary in width but are generally between 5 and 30 feet wide weighing at least 1000 lbs or more. Larger units are used by some farmers that employ several cylinders linked together to cover large areas more quickly. Many designs allow more weight by filling the metal drum with water. The energy required to operate a roller/crimper is similar to that required for a cultipacker and tenfold less than the energy required for mowing (Anonymous 2002). The rolled cover crop system can save organic soybean farmers up to 5- gallons of fuel per acre by reducing tillage operations (Mutch 2004) and when averaged over a three year corn-soybean-wheat rotation, no-till planting with a roller uses 25% less energy than traditional organic management (Ryan et al. 2009).

Where They Work

Cover crop rollers can be effective for terminating annual crops including cereal grains; rye, wheat, oats, and barley as well as annual legumes and other forbs. Most of the research with roller/crimpers has been with cereal grain cover crops, although legume cover crops such as hairy vetch, winter pea, and crimson clover have also been evaluated (Wilson 2007, unpublished). Previous work showed that control of cereal cover crops improves with increasing plant maturity (Ashford and Reeves, 2004). The cereal grain generally needs to be well into flowering in order for the roller-crimper to provide acceptable control alone. Mirsky et al. (2009) reported that cereal rye was consistently controlled at Zadoks growth stage 61, when the anthers were clearly visible and shed- ding pollen. Rolling prior to this growth stage did not consistently prevent the rye cover crop from competing with the cash crop and producing viable seed. Cereal rye maturity and thus the time one must wait until it reaches the susceptible growth stage for control will depend on several factors including the fall seeding date and the temperature in the fall and spring (Figure 1). These dates will vary somewhat by year and can be delayed in the spring as we move north geographically.

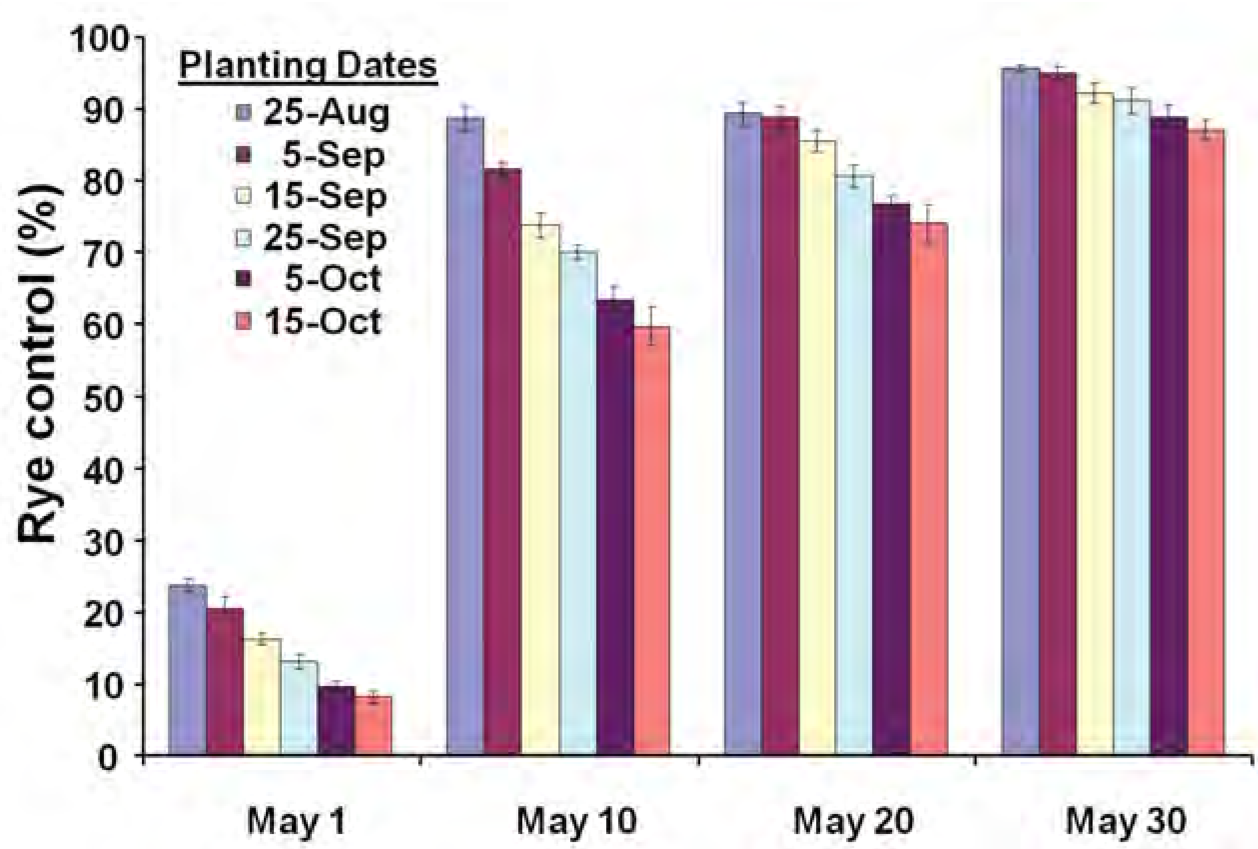
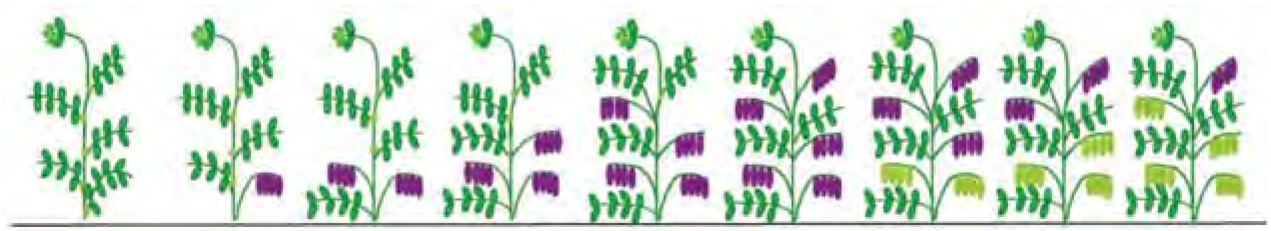


Figure 1. Percent control of cereal rye 6 weeks after rolling as influenced by planting date (Aug. 25-Oct. 15) and termination date (May 1-May 30). Bars represent standard error of the means. By the May 30 termination, fall planting date was not important--all dates were effectively controlled. Experiment was conducted in conducted in Central Pennsylvania in 2005 and 2006 (Mirsky et al. 2009).

Hairy vetch is another common cover crop that can be successfully terminated with a roller crimper. Research by Mischler et al. 2009 reported that consistent hairy vetch control was achieved when small pods were visible (early pod set) on the upper nodes of the plant counting down from the top (Figure 2). Although acceptable control was sometimes achieved prior to this growth stage, some regrowth occurred at some locations. Incomplete control of vetch increases the risk for vetch seed production, which can be a serious problem in subsequent winter annual crops such as wheat. The roller crimper can also work well on mixtures of cereals and legumes such as hairy vetch seeded with rye, wheat, or triticale. The timing of the operation should be based on the latest maturing species or multiple passes with a roller may be necessary. A number of cover crops are not controlled by the roller crimper including biennial or perennial legumes (alfalfa, red clover, etc.), canola, and annual ryegrass to name just a few. More cover crop species need to be tested for their suitability for using a roller-crimper.



Vege-tative 1	20% Flower 2	40% Flower 3	60% Flower 4	80% Flowe r 5	100% Flower 6	Early Pod 7	Mid Pod 8	Late Pod 9

Figure 2. Hairy vetch growth stages based on the upper five nodes of the vine. Growth stage depends on the number of buds that have begun to bloom or produce pods. Vegetative (1), no flower buds are visible; early pod set (7), when 1-2 pods are visible; and late pod set (9) when 4+ pods are visible. Consistent control with the roller-crimper was achieved at early pod set (7).

Combinations with Herbicides

Although much of the interest in the roller-crimper in North America comes from organic farmers that do not use herbicides, there is some potential to combine herbicides with the roller and use an integrated approach. This has been the basis for their use in South America where burndown herbicides are generally used. Some research has shown that the roller-crimper in combination with a burndown herbicide like glyphosate can increase the effectiveness of cover crop control. In a study by Ashford and Reeves 2003, the roller in combination with a half rate of herbicide equaled the effectiveness of the herbicide alone at the full rate. In research by Curran et al. 2007, reduced rates of glyphosate in combination with the roller desiccated cereal rye more quickly than the herbicide alone. Several weeks after application, rye control was similar between rolled and unrolled treatments that included glyphosate. Although not tested in the previous study, the rolled cover crop mat potentially provides greater weed suppression than a more upright unrolled cover due to reductions in weed emergence and reduced competition. Finally, the combination of a burndown herbicide plus the roller alleviates the need to "wait" until the cover crop is susceptible to control by the roller alone and can provide an earlier window for cash crop establishment. Small grain cover crops should be in the late boot stage or in early heading to benefit from rolling. Rolling prior to this does not generally provide sufficient cover crop biomass nor the quality (higher fiber content) necessary to suppress weeds or persist long enough to impact weed emergence. In some soybean research by Mischler et al. 2010, a sprayed and rolled rye cover crop at the late boot stage or beyond provided weed control results similar to a postemergence glyphosate and no cover in 2 of 4 study locations.

Need for Good No-till Equipment

High-residue conservation tillage requires planting equipment that is capable of slicing through the rolled cover crop residue, accurately placing seeds in the soil, and then covering the seed with soil. In vegetable transplant systems, similar results with seedlings are desired. Although the no-till industry has made great strides in the past 15 years toward developing planters and drills that can handle large amounts of plant residue, there continues to be challenges when establishing cash crops in large amounts of residue. Too wet or too dry soil conditions, lodged cereal cover crops at the time of rolling, and extreme amounts (greater than 10,000 lb DM/acre) of cover crop biomass can make direct seeding particularly challenging. We have been more successful using no-till planters than no-till drills where depth of seed placement can be more problematic. **Be sure to test, adjust, and refine your planting equipment prior to adopting high-residue**

no-till management. Establishment of the cash crop is critical to success for this no-till system.

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b

FACT SHEET

Agriculture and Natural Resources

SAG-10-09
AEX-543-09

The Biology of Soil Compaction

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Soil Compaction

Soil compaction is a common and constant problem on most farms that till the soil. Heavy farm machinery can create persistent subsoil compaction (Hakansson and Reeder, 1994). Johnson et al. (1986) found that compacted soils resulted in: (a) restricted root growth; (b) poor root zone aeration; and (c) poor drainage that results in less soil aeration, less oxygen in the root zone, and more losses of nitrogen from denitrification.

Subsoil tillage has been used to alleviate compaction problems. Subsoilers are typically operated at depths of 12 to 18 inches to loosen the soil, alleviate compaction, and increase water infiltration and aeration. Subsoiling usually increases crop yields but the effects may only be temporary as the soil re-compacts due to equipment traffic. Some no-till fields never need to be subsoiled, but in other no-till fields deep tillage has increased yields especially if equipment traffic is random. When subsoiling removes a hard pan, traffic must be controlled or compaction will reoccur. If a hard pan does not exist, equipment traffic generally will create one (Reeder and Westermann, 2006).

If the soil is subsoiled when the soil is wet, additional compaction may occur. In a loamy sand, Busscher et al. (2002) found that soil compaction increased with time, and cumulative rainfall accounted for 70 to 90 percent of the re-compaction due to water filtering through the soil and the force of gravity. The fuel, labor, equipment, and time to subsoil makes it an expensive operation. Subsoiling in dry conditions requires even more fuel (Reeder and Westermann, 2006). Two other factors that impact soil compaction are rainfall impact and gravity. In soils that have been tilled, both the velocity of the raindrop impact on bare soil and natural gravity combine to compact soils.

Low organic matter levels make the soil more susceptible to soil compaction. Organic residues on the soil surface have been shown to cushion the effects of soil compaction. Surface organic residues have the ability to be compressed but they also retain their shape and structure once the traffic has passed. Like a sponge, the organic matter is compressed and then springs back to its normal shape. However, excessive traffic will break up organic residues, and tillage accelerates the decomposition of organic matter. Organic residues in the soil profile may be even more important than surface organic residues. Organic matter (plant debris and residues) attached to soil particles (especially clay particles) keeps soil particles from compacting. Organic matter binds microaggregates and macroaggregates in the soil. Low organic matter levels make the soil more susceptible to soil compaction (Wortman and Jasa, 2003).

In the last hundred years, tillage has decreased soil organic levels by 60%, which means that approximately 40% soil organic carbon stocks are remaining (International Panel on Climate Change, 1996, Lal, 2004). Carbon provides energy for soil microbes, is a storehouse for nutrients, and keeps nutrients recycling within the soil. Humus or old carbon (>1,000 years old) is the most stable carbon and binds micro soil particles together to form microaggregates. Humus is non-water soluble so it stabilizes microaggregates and is not readily consumed by microorganisms. Humus is more resistant to tillage and degradation than active carbon.

Active carbon (plant sugars or polysaccharides, glomalin) is consumed by microbes for energy. Active carbon is reduced with tillage but is stabilized under natural vegetation and no-till systems using a continuous living cover. Active carbon is part of the glue that binds microaggregates into macroaggregates and insulates the macroaggregate from oxygen. Soil porosity, water infiltration, soil aeration, and soil structure increase under natural vegetation and no-till systems with continuous living cover. Increased soil macroaggregation improves soil structure and lowers bulk density, keeping the soil particles from compacting.

Microaggregates and Macroaggregate Formation

Microaggregates are 20–250 µm in size and are composed of clay microstructures, silt-size microaggregates, particulate organic matter, plant and fungus debris, and mycorrhizal fungus hyphae: these particles are stable in size. Roots and microbes combine microaggregates in the soil to form macroaggregates. Macroaggregates are linked mainly by fungi hyphae, roots fibers, and polysaccharides and are less stable than microaggregates. Macroaggregates are greater than 250 µm in size and give soil its structure and allow air and water infiltration. Compacted soils tend to have more microaggregates than macroaggregates. See the microaggregate-macroaggregate model (figure 1) and the macroaggregate model and hierarchy (figure 2).

Glomalin acts like a glue to cement microaggregates together to form macroaggregates and improve soil structure. Glomalin initially coats the plant roots and then coats soil particles. Glomalin is an amino polysaccharide or glycoprotein created by combining a protein from the mycorrhizal fungus with sugar from plant root exudates (Allison, 1968). The fungal *"root-hyphae-net"* holds the aggregates intact and clay particles protect the roots and hyphae from attack by microorganisms. Roots also create other polysaccharide exudates to coat soil particles (see figures 2 and 3).

The contribution of mycorrhizal fungi to aggregation is a simultaneous process involving three steps. First, the fungus hyphae form an entanglement with primary soil particles, organizing and bringing them together. Second, fungi physically protect the clay particles and the organic debris that form microaggregates. Third, the plant root and fungus hyphae form glomalin and glue microaggregates and some smaller macroaggregates together to form larger macroaggregates (see figure 4).

In order for glomalin to be produced, plants and mycorrhizal fungus must exist in the soil together. Glomalin needs to be continually produced because it is readily consumed by bacteria and other microorganisms in the

Microaggregates-Macroaggregates Model

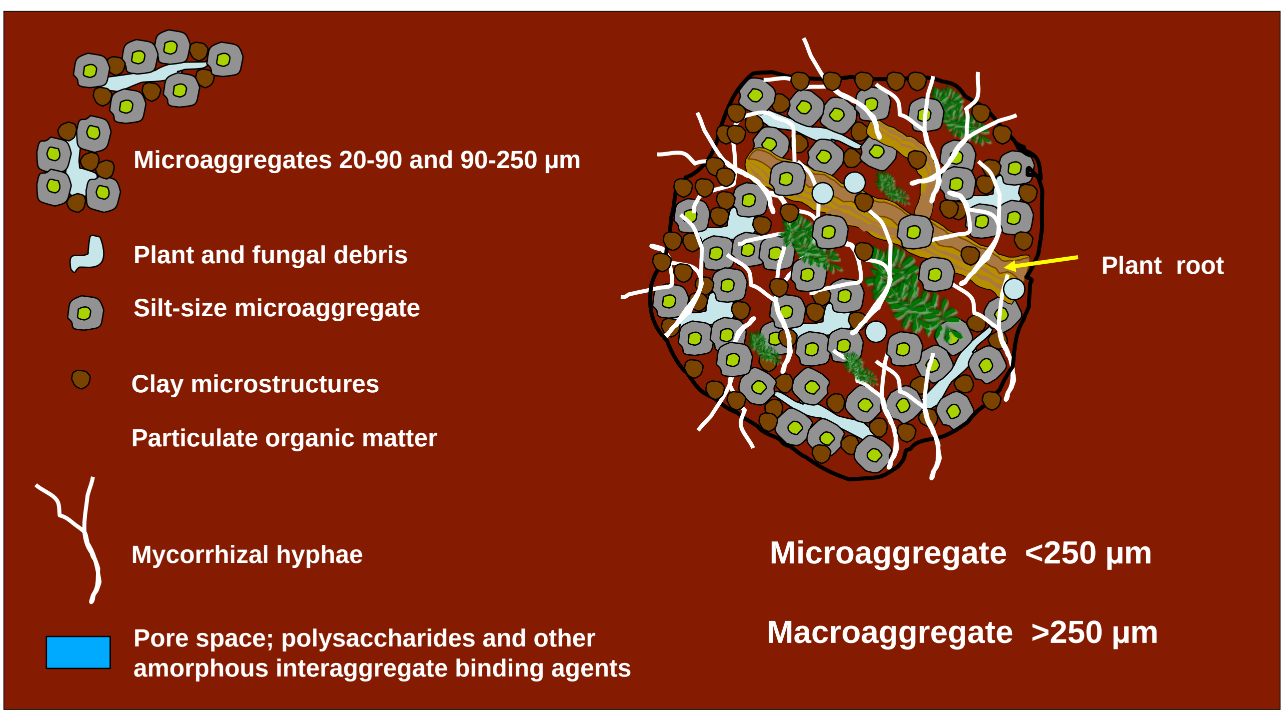

Figure 1. Dr. Charles Rice presentation adapted from Jastrow and Miller, 1997.

Macroaggregate Model and Hierarchy

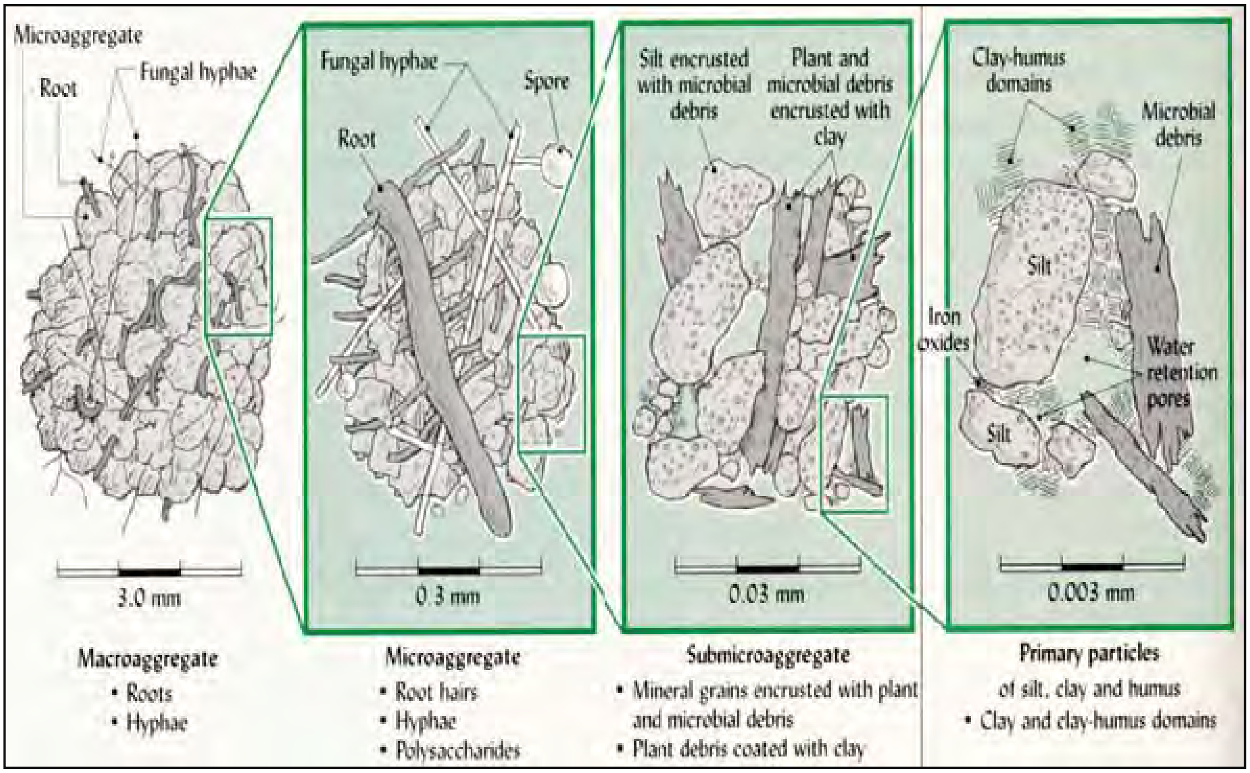

Figure 2. From Tisdall & Oades, 1982.

soil. Bacteria thrive in tilled soils because they are more hardy and smaller than fungus, so bacteria numbers increase in tilled soils. Fungi live longer and need more stable conditions to survive. Fungi grow better under no-till soil conditions with a continuous living cover and a constant source of carbon. Since fungi do not grow as well in tilled soils, less glomalin is produced and fewer macroaggregates are formed. Fewer macroaggregates is associated with poor soil structure and compaction. **Thus, soil compaction is a biological problem related to decreased production of polysaccharides and glomalin in the soil. Soil compaction is due to a lack of living roots and mycorrhizal fungus in the soil.**

In a typical corn-soybean rotation, active roots are present only a third of the time. Adding cover crops between the corn and soybean crops increases the presence of active living roots to 85% to 90% of the time. Active roots produce more amino polysaccharides and glomalin because mycorrhizal fungus populations increase due to a stable food supply.

Surface and subsoil tillage may physically break up hard pans and soil compaction temporarily but they are not a permanent fix. Tillage increases the oxygen content of soils and decreases glomalin and amino polysaccharide production by reducing plant root exudates and mycorrhizal fungus populations. Soil compaction is a result of the lack of active roots producing polysaccharides and root exudates, and a lack of mycorrhizal fungus producing glomalin. In a typical undisturbed soil, fungal hyphae are turned over every 5 to 7 days and the glomalin in the fungal hyphae is decomposed and continually coats the soil particles. Disturbed soils have less fungus, more bacteria, and more microaggregates than macroaggregates. Heavy equipment loads push the microaggregates together so that they can chemically bind together, compacting the soil. Macroaggregate formation improves soil structure so that soil compaction may be minimized. Thus, soil compaction has a biological component (see figure 5).

Cultivation of soils, heavy rains, and oxygen promotes the breakdown of macroaggregates, which give soil structure and soil tilth. Farmers who excessively till their soils (for example, heavy disking or plowing) break down the soil structure by breaking up the macroaggregates, injecting oxygen into the soil, and depleting the soil of glomalin and polysaccharides and a loss of carbon. Greater than 90% of the carbon in soil is associated with the mineral fraction (Jastrow and Miller, 1997). Glomalin and polysaccharides are consumed by flourishing

Figure 3. Roots, fungi hyphae. and polysaccharides stabilize soil macroaggregates and promote good soil structure. From Dr. João de Moraes Sá.

bacteria populations that thrive on high oxygen levels in the soil and the release of nutrients in organic matter from the tillage. The end result is a soil composed of mainly microaggregates and cloddy compacted soils. Soils composed mainly of microaggregates prevent water infiltration due to the lack of macropores in the soil, so water tends to pond on the soil surface. Farm fields that have been excessively tilled tend to crust, seal, and compact more than no-till fields with surface crop residues and a living crop with active roots to promote fungal growth and glomalin production.

An agricultural system that combines a **continuous living cover (cover crops) with continuous long-term no-till** is a system that closely mimics a natural system and should restore soil structure and soil productivity. A continuous living cover plus continuous long-term no-till protects the soil from compaction in five major ways. **First**, the soil surface acts like a sponge to help adsorb the weight of heavy equipment traffic. **Second**, plant roots create voids and macropores in the soil so that air and water can move through the soil. Roots act like a biological valve to control the amount of oxygen that enters the soil. The soil needs oxygen for root respiration and to support aerobic microbes in the soil. However, too much soil oxygen results in excessive carbon loss from the aerobic microbes consuming the active carbon. **Third**, plant roots

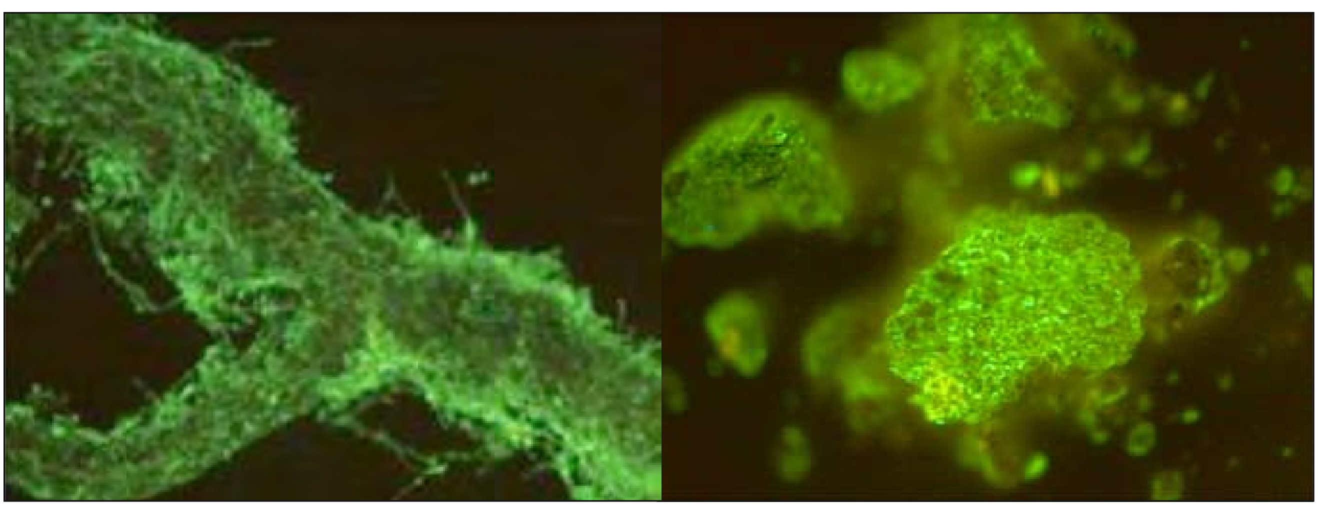

Figure 4. Glomalin surrounding a root heavily infected with mycorrhizal fungi and soil macroaggregates surrounded by glomalin. Photos by Dr. Sara Wright, USDA-ARS.

What is a clod?

Many farmers complain that their soil is cloddy and hard to work. Clods are manmade and do not usually exist in the natural world. Bricks and clay tile are formed by taking wet clay from the soil, and heating and drying the clay. When farmers till the soil, they perform the same process by exposing the clay to sunlight, heating and drying the clay until it gets hard and turns into a clod. Tillage also oxidizes the soil and results in increased microbial decomposition of organic residues. Organic residues keep clay particles from chemically binding. Clay soils that remain protected by organic residues and stay moist resist turning into clods because the moisture and organic residues keep the clay particles physically separated.

Organic residues act like sponges, absorbing water and soil nutrients, cushioning soil particles. Clods act like bricks, resisting water absorption and making soils hard and compacted. Photo by Jim Hoorman.

supply food for microorganisms (especially fungus) and burrowing soil fauna that also keep the soil from compacting. **Fourth**, organic residues left behind by the decaying plants, animals, and microbes are lighter and less dense than clay, silt, and sand particles. The average bulk density of soil organic matter is 0.3 to 0.6 kg/m^3 compared to soil density of 1.4 to 1.6 kg/m^3. So adding organic residues to the soil decreases the average soil density. **Fifth**, soil compaction is reduced by combining microaggregates into macroaggregates in the soil. Microaggregate soil particles (clay, silt, particulate organic matter) are held together by humus or old organic matter residues, which are resistant to decomposition, but microaggregates tend to compact in the soil under heavy equipment loads. Polysaccharides and glomalin weakly combine microaggregates into macroaggregates but this process is broken down once the soil is disturbed or tilled.

Oxidation and Release of CO_2

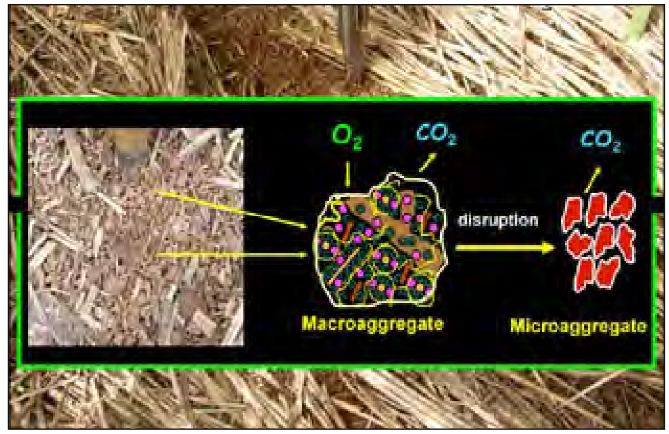

Figure 5. Tillage disrupts the macroaggregates and breaks them into microaggregates by letting in oxygen and releasing carbon dioxide. From Dr. João de Moraes Sá.

Summary

Soil compaction reduces crop yields and farm profits. For years, farmers have been physically tilling and subsoiling the soil to reduce soil compaction. At best, tillage may temporarily reduce soil compaction but rain, gravity, and equipment traffic compact the soil. Soil compaction has a biological component and the root cause of soil compaction is a lack of actively growing plants and active roots in the soil. A continuous living cover plus long-term continuous no-till reduce soil compaction in five ways. Organic residues on the soil surface cushion the soil from heavy equipment. Plant roots create voids and macropores in the soil for air and water movement. Plant roots act like a biological valve to control the amount of oxygen in the soil to preserve soil organic matter. Plant roots supply food for soil microbes and soil fauna. Residual organic soil residues (plants, roots, microbes) are lighter and less dense than soil particles.

Soil compaction is reduced by the formation of macroaggregates in the soil. Microaggregate soil particles (clay, silt, particulate organic matter) are held together by humus or old organic matter residues and are resistant to decomposition. Macroaggregates form by combing microaggregates together with root exudates like polysaccharides and glomalin (sugars from plants and protein from mycorrhizal fungus). Polysaccharides from plants and glomalin from fungus weakly hold the microaggregates together but are consumed by bacteria so they need to be continually reproduced in the soil to improve soil structure. Tillage and subsoiling increases the

continued on page 7

Building Soil Structure

Building soil structure is like building a house. Mother Nature is the architect and plants and microbes are the carpenters. Every house needs to start out with a good foundation like bricks *(clay, sand, silt)* and cement *(cations like Ca++, K+).* When a house is framed, various sized wood timbers, rafters, and planks are used to create rooms (represented by the various sized roots in the soil). Wood and roots give the house and the soil structure, creating space where the inhabitants (plants, microbes, and soil fauna) can live.

Wood in a house is held together by various sized nails *(humus)* and lag screws *(phosphate* attaches organic residues to clay particles). A house has braces to add stability *(nitrogen* and *sulfur* provide stability to organic residues) and a roof to control the temperature and moisture. In the soil, a deep layer of surface residues controls oxygen and regulates water infiltration and runoff. A roof insulates the house and regulates the temperature just like surface residue on the soil surface keeps the soil temperature in a comfortable range for the inhabitants *(microbes* and *plant roots).* Houses need insulation and glue to keep the house together. Root exudates form polysaccharides and glomalin (formed with *mycorrhizal fungus)* to insulate the soil particles and keep the soil macroaggregates glued together. If the roof on a house is destroyed, moisture and cold air can enter the house and rot out the wood and dissolve the glues.

In the soil, organic matter decomposes very quickly when tillage, excess oxygen, and moisture either break down the glues *(polysaccharides* and *glomalin)* or are easily consumed by flourishing bacteria populations. Excess oxygen in the soil (from tillage) stimulates bacteria populations to grow and they consume the polysaccharides as a food source, destroying the soil structure. With tillage, macroaggregates become microaggregates and the soil becomes compacted.

As every homeowner knows, houses need regular maintenance. In the soil, the roots and the microbes (especially *fungus)* are the carpenters that maintain their house, continually producing the glues *(polysaccharides* and *glomalin)* that hold the house together. Regular tillage acts like a tornado or a hurricane, destroying the structural integrity of the house and killing off the inhabitants. Tillage oxidizes the organic matter in the soil, destroying the roots and the active organic matter, causing the soil structure to crumble and compact. If you remove wood supports and glue in a house, the house becomes unstable just like the soil does when you remove the active living roots and active organic residues (polysaccharides). Wood beams in a coal mine stabilize the coal mine tunnel like active living roots and healthy microbial communities give the soil structure to prevent soil compaction. Active roots and macroaggregates give soil porosity to move air and water through the soil in macropores. In an ideal soil, 50 to 60% of the soil volume is porous while in a degraded compacted soil, soil porosity may be reduced to 30 to 40% of the total soil volume. Compacted soil is like a decaying house turning to a pile of bricks, cement, and rubble.

Building Soil Structure is like Building a House

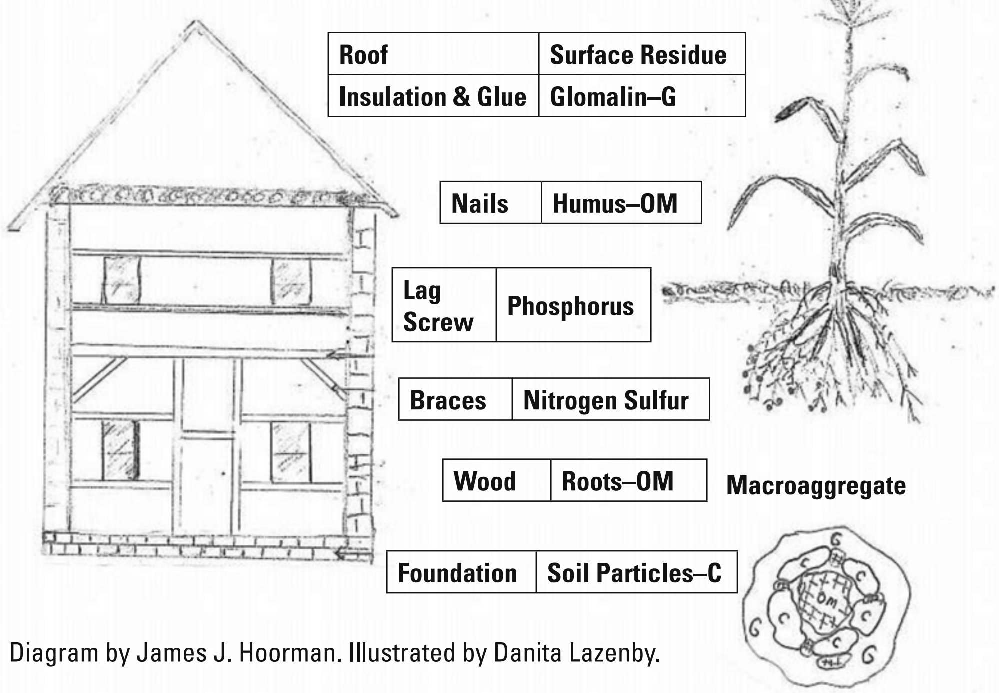

Diagram by James J. Hoorman. Illustrated by Danita Lazenby.

oxygen content in soils, increasing bacteria populations, which consume the active carbon needed to stabilize macroaggregates, leading to the destruction of soil structure. Soil compaction is a direct result of tillage, which destroys the active organic matter and a lack of living roots and microbes in the soil. Heavy equipment loads push soil microaggregates together so that they chemically bind together, resulting in soil compaction.

Acknowledgments

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Five Ways Soil Organic Matter Resists Soil Compaction

1. Surface residue resists compaction. Acts like a sponge to absorb weight and water.
2. Organic residues are less dense (0.3-0.6 g/cm^3) than soil particles (1.4-1.6 g/cm^3).
3. Roots create voids and and spaces for air and water.
4. Roots act like a biological valve to control oxygen in the soil.
5. Roots supply exudates to glue soil particles together to form macroaggregates and supply food for microbes.

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- Sustainable Crop Rotations with Cover Crops
- Understanding Soil Ecology and Nutrient Recycling
- Homegrown Nitrogen
- Using Cover Crops to Improve Soil and Water Quality
- Using Cover Crops to Convert to No-till

b

THE OHIO STATE UNIVERSITY EXTENSION

FACT SHEET

Agriculture and Natural Resources

SAG-16-10

Understanding Soil Microbes and Nutrient Recycling

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Soil Microbes and Nutrient Recycling

Soil microorganisms exist in large numbers in the soil as long as there is a carbon source for energy. A large number of bacteria in the soil exists, but because of their small size, they have a smaller biomass. Actinomycetes are a factor of 10 times smaller in number but are larger in size so they are similar in biomass to bacteria. Fungus population numbers are smaller but they dominate the soil biomass when the soil is not disturbed. Bacteria, actinomycetes, and protozoa are hardy and can tolerate more soil disturbance than fungal populations so they dominate in tilled soils while fungal and nematode populations tend to dominate in untilled or no-till soils.

There are more microbes in a teaspoon of soil than there are people on the earth. Soils contain about 8 to 15 tons of bacteria, fungi, protozoa, nematodes, earthworms, and arthropods. See fact sheets on Roles of Soil Bacteria, Fungus, Protozoa and Nematodes.

Table 1: Relative number and biomass of microbial species at 0–6 inches (0–15 cm) depth of soil

Microorganisms	Number/g of soil	Biomass (g/m^2)
Bacteria	10^8–10^9	40–500
Actinomycetes	10^7–10^8	40–500
Fungi	10^5–10^6	100–1500
Algae	10^4–10^5	1–50
Protozoa	10^3–10^4	Varies
Nematodes	10^2–10^3	Varies

Microbial Soil Organic Matter Decomposition

Organic matter decomposition serves two functions for the microorganisms, providing energy for growth and suppling carbon for the formation of new cells. Soil organic matter (SOM) is composed of the “living” (microorganisms), the “dead” (fresh residues), and the “very dead” (humus) fractions. The “very dead” or humus is the long-term SOM fraction that is thousands of years old and is resistant to decomposition. Soil organic matter has two components called the active (35%) and the passive (65%) SOM. Active SOM is composed of the “living” and “dead” fresh plant or animal material which is food for microbes and is composed of easily digested sugars and proteins. The passive SOM is resistant to decomposition by microbes and is higher in lignin.

Microbes need regular supplies of active SOM in the soil to survive in the soil. Long-term no-tilled soils have significantly greater levels of microbes, more active carbon, more SOM, and more stored carbon than conventional tilled soils. A majority of the microbes in the soil exist under starvation conditions and thus they tend to be in a dormant state, especially in tilled soils.

Dead plant residues and plant nutrients become food for the microbes in the soil. Soil organic matter (SOM) is basically all the organic substances (anything with carbon) in the soil, both living and dead. SOM includes plants, blue green algae, microorganisms (bacteria, fungi, protozoa, nematodes, beetles, springtails, etc.) and the fresh and decomposing organic matter from plants, animals, and microorganisms.

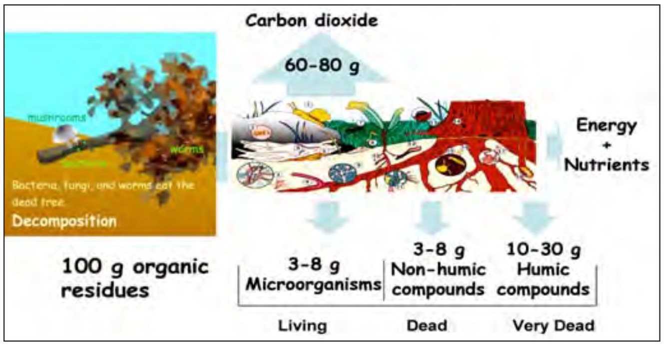


Diagram by Dr. Rafiq Islam

Soil organic matter can be broken down into its component parts. One hundred grams (g) or 100 pounds (lbs) of dead plant material yields about 60–80 g (lbs) of carbon dioxide, which is released into the atmosphere. The remaining 20–40 g (lbs) of energy and nutrients is decomposed and turned into about 3–8 g (lbs) of microorganisms (the living), 3–8 g (lbs) of non-humic compounds (the dead), and 10–30 g (lbs) of humus (the very dead matter, resistant to decomposition). The molecular structure of SOM is mainly carbon and oxygen with some hydrogen and nitrogen and small amounts of phosphorus and sulfur. Soil organic matter is a by-product of the carbon and nitrogen cycles.

Soil Organic Matter Nutrients

The nutrients in the soil have a current value of $680 for each 1% SOM or $68 per ton of SOM based on economic values for commercial fertilizer (see Table 2). SOM is composed of mostly carbon but associated with the carbon is high amounts of nitrogen and sulfur from proteins, phosphorus, and potassium. SOM should be considered like an investment in a certificate of deposit (CD). Soils that are biologically active and have higher amounts of active carbon recycle and release more nutrients for plant growth than soils that are biologically inactive and contain less active organic matter. Under no-till conditions, small amounts of nutrients are released annually (like interest on a CD) to provide nutrients slowly and efficiently to plant roots. However, with tillage, large amounts of nutrients can be released since the SOM is consumed and destroyed by the microbes. Since SOM levels are slow to build, the storage capacity for nutrients is decreased and excess nutrients released are often leached to surface waters. SOM is a storehouse for many plant nutrients.

Consider the following three scenarios. Soils typically turnover 1 to 3% of their nitrogen stored in SOM. Tilled or unhealthy soils release a lower percent of nitrogen due to lower microbial activity. A tilled soil with 2% SOM (2,000 lbs of N) may release 1% N or 20 lbs of N per year. A soil that is more biologically active and has 4% SOM (4,000 lbs N) may release 1.5% N or 60 lbs N while a 6% SOM soil (6,000 lbs N) may release 2% N or 120 lbs of N. In tilled soils, excess nutrients released are often lost and the carbon stores are depleted so that future storage of nutrients is reduced. Farmers often see this occur when they till a virgin soil, an old pasture, or a fence row. For several years, crops on the newly tilled soil will grow better than the surrounding soils, but over time the soil will be depleted of carbon and the newly tilled soil will become less fertile because the carbon is oxidized as carbon dioxide and lost to the atmosphere. Tillage results in the oxidation and destruction of carbon in the soil by increasing the soil oxygen levels, thereby promoting bacteria populations to expand and consume active carbon in the soil.

Table 2: Value of Soil Organic Matter

Assumptions: 2,000,000 pounds soil in top 6 inches	
Nutrients	1% organic matter = 20,000# 50% Carbon, C:N ratio = 10:1
Nitrogen:	1000# * $0.50/#N = $500
Phosphorus:	100# * $.70/#P = $70
Potassium:	100# * $0.40/#K = $40
Sulfur:	100# * $0.50/#S = $50
Carbon:	10,000# or 5 ton * $4/Ton = $20
Value of 1% SOM Nutrients/Acre	= $680
Relative Ratio of Nutrients:	100 Carbon/10 Nitrogen/ 1 Phosphorus/1 Potassium/1 Sulfur

Climate, Temperature, and pH Effects on SOM

SOM is affected by climate and temperature. Microbial populations double with every 10 degree Fahrenheit change in temperature. If we compare the tropics to colder arctic regions, we find most of the carbon is tied up in trees and vegetation above ground. In the tropics, the topsoil has very little SOM because high temperatures and moisture quickly decompose SOM. Moving north or south from the equator, SOM increases in the soil. The tundra near the Arctic Circle has a large amount of SOM because of cold temperatures. Freezing temperatures change the soil so that more SOM is decomposed then in soils not subject to freezing.

Moisture, pH, soil depth, and particle size affect SOM decomposition. Hot, humid regions store less organic carbon in the soil than dry, cold regions due to increased microbial decomposition. The rate of SOM decomposition increases when the soil is exposed to cycles of drying and wetting compared to soils that are continuously wet or dry. Other factors being equal, soils that are neutral to slightly alkaline in pH decompose SOM quicker than acid soils; therefore, liming the soil enhances SOM decomposition and carbon dioxide evolution. Decomposition is also greatest near the soil surface where the highest concentration of plant residues occur. At greater depths there is less SOM decomposition, which parallels a drop in organic carbon levels due to less plant residues. Small particle sizes are more readily degraded by soil microbes than large particles because the overall surface area is larger with small particles so that the microbes can attack the residue.

A difference in soil formation also occurs traveling east to west across the United States. In the east, hardwood forests dominated and tree tap roots were high in lignin, and deciduous trees left large amounts of leaf litter on the soil surface. Hardwood tree roots do not turn over quickly so organic matter levels in the subsoil are fairly low. In forest soils, most of the SOM is distributed in the top few inches. As you move west, tall grassland prairies dominated the landscape and topsoil formed from deep fibrous grass root systems. Fifty percent of a grass root dies and is replaced every year and grass roots are high in sugars and protein (higher active organic matter) and lower in lignin. So soils that formed under tall grass prairies are high in SOM throughout the soil profile. These prime soils are highly productive because they have higher percentage of SOM (especially active carbon), hold more nutrients, contain more microbes, and have better soil structure due to larger fungal populations.

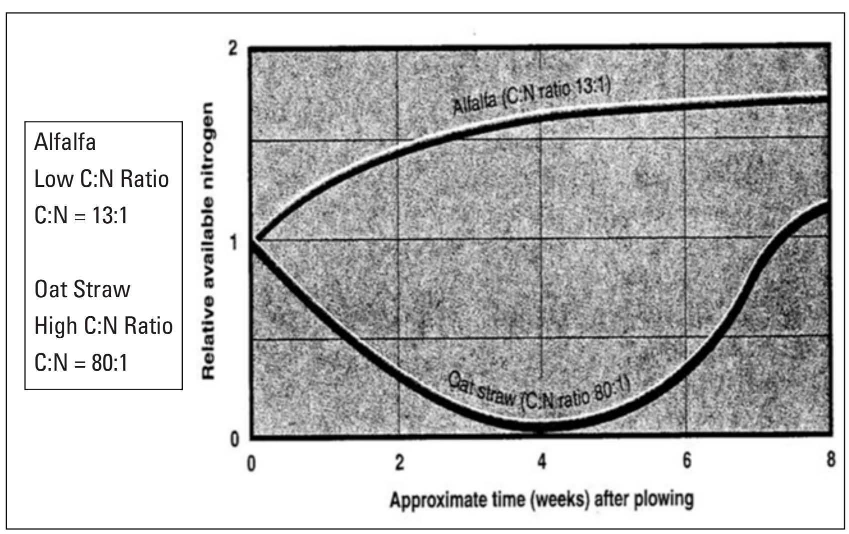
Carbon to Nitrogen Ratio

The break down of organic residues by microbes is dependant upon the carbon to nitrogen (C:N) ratio. Microbes in a cow's rumen, a compost pile, and soil microbes rely on the C:N ratio to break down organic (carbon-based) residues. Consider two separate feed sources, a young tender alfalfa plant and oat or wheat straw. A young alfalfa plant has more crude protein, amino acids, and sugars in the stalk so it is easily digested by microbes whether it is in a cow's rumen, a compost pile, or in the soil. Young alfalfa has a high nitrogen content from protein (amino acids and proteins are high in nitrogen and sulfur), so it has a lower carbon to nitrogen ratio (less carbon, more nitrogen). However, oat and wheat straw (or older mature hay) has more lignin (which is resistant to microbial decomposition), lower crude protein, and less sugars in the stalk and a higher C:N ratio. Straw is decomposed by microbes but it takes additional time and nitrogen to break down this high carbon source.

A low nitrogen content or a wide C:N ratio is associated with slow SOM decay. Immature or young plants have a higher nitrogen content, lower C:N ratios and faster SOM decay. For good composting, a C:N ratio less than 20 allows the organic materials to decompose quickly (4 to 8 weeks) while a C:N ratio greater than 20 requires additional N and slows down decomposition. So if we add a high C based material with low N content to the soil, the microbes will tie up soil nitrogen. Eventually, the soil N is released but in the short-term the N is tied up. The conversion factor for converting N to crude protein is 16.7, which relates back to why it is so important to have a C:N ratio of less than 20.

The C:N ratio of most soils is around 10:1 indicating that N is available to the plant. The C:N ratio of most plant residues tends to decrease with time as the SOM decays. This results from the gaseous loss of carbon dioxide. Therefore, the percentage of nitrogen in the residual SOM rises as decomposition progresses. The 10:1 C:N ratio of most soils reflects an equilibrium value associated with most soil microbes (Bacteria 3:1 to 10:1, Fungus 10:1 C:N ratio).

Bacteria are the first microbes to digest new organic plant and animal residues in the soil. Bacteria typically can reproduce in 30 minutes and have high N content in their cells (3 to 10 carbon atoms to 1 nitrogen atom or 10 to 30% nitrogen). Under the right conditions of heat, moisture, and a food source, they can reproduce very



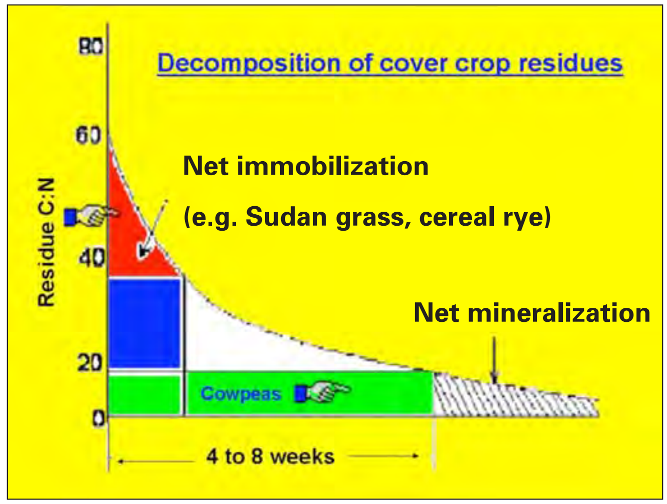
Graph of Relative Available N with Length of Time for Decomposition quickly. Bacteria are generally less efficient at converting organic carbon to new cells. Aerobic bacteria assimilate about 5 to 10 percent of the carbon while anaerobic bacteria only assimilate 2 to 5 percent, leaving behind many waste carbon compounds and inefficiently using energy stored in the SOM.

Fungus generally release less carbon dioxide into the atmosphere and are more efficient at converting carbon to form new cells. The fungus generally captures more energy from the SOM as they decompose it, assimilating 40 to 55 percent of the carbon. Most fungi consume organic matter higher in cellulose and lignin, which is slower and tougher to decompose. The lignin content of most plant residues may be of greater importance in predicting decomposition velocity than the C:N ratio.

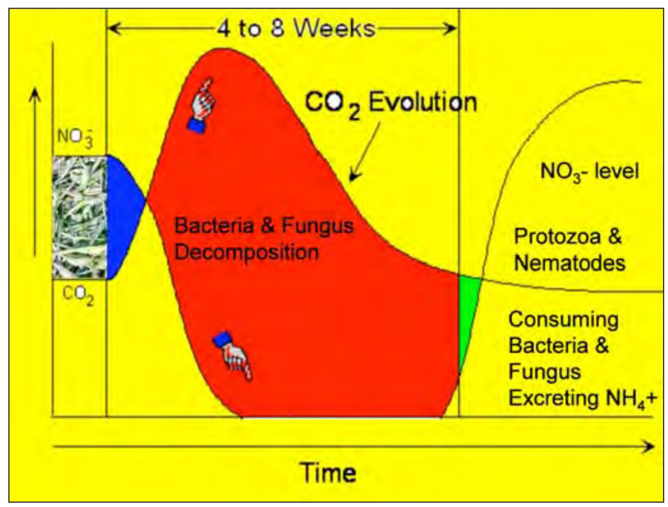
Mycorrhizal fungi live in the soil on the surface of or within plant roots. The fungi have a large surface area and help in the transport of mineral nutrients and water to the plants. The fungus life cycle is more complex and longer than bacteria. Fungi are not as hardy as bacteria, requiring a more constant source of food. Fungi population levels tend to decline with conventional tillage. Fungi have a higher carbon to nitrogen ratio (10:1 carbon to nitrogen or 10% nitrogen) but are more efficient at converting carbon to soil organic matter. With high C:N organic residues, bacteria and fungus take nitrogen out of the soil (see the graph on net immobilization).

Protozoa and nematodes consume other microbes. Protozoa can reproduce in 6–8 hours while nematodes take from 3 days to 3 years with an average of 30 days to reproduce. After the protozoa and nematodes consume the bacteria or other microbes (which are high in nitrogen), they release nitrogen in the form of ammonia (see the graph on net mineralization). Ammonia (NH_4+) and soil nitrates (NO_3-) are easily converted back and forth in the soil. Plants absorb ammonia and soil nitrates for food with the help of the fungi mycorrhizal network.

Microorganism populations change rapidly in the soil as SOM products are added, consumed, and recycled. The amount, the type, and availability of the organic matter will determine the microbial population and how it evolves. Each individual organism (bacteria, fungus, protozoa) has certain enzymes and complex chemical reactions that help that organism assimilate carbon. As waste products are generated and the original organic residues are decomposed, new microorganisms may take over, feeding on the waste products, the new flourishing microbial community (generally bacteria), or the more resistant SOM. The early decomposers generally attack the easily digested sugars and proteins followed by microorganisms that attack the more resistant residues.



Decomposition of Cover Crop Residues: Cowpeas with a low C:N ratio (<20) will decompose in 4 to 8 weeks and result in net mineralization or release of N. Sudan grass or cereal rye with a higher C:N ratio (>38) will decompose slowly (3 months to 1 year or more) and will result in net immobilization or will tie up soil N. Graph by Dr. Rafiq Islam.



Graph of Cowpeas (C:N<20) being decomposed by bacteria and fungus, the carbon dioxide evolution and protozoa and nematodes consuming the bacteria and fungus and excreting ammonia into the soil for plant growth. NO_3- and NH_4+ are easily converted in the soil. Graph by Dr. Rafiq Islam.

Cover crops supply food (active carbon like glucose and proteins) to the microbes to feed on. In the soil, there are 1,000 to 2,000 times more microbes associated with roots than are living in bare or tilled soil. The microbes in turn build SOM and store soil nutrients. Building SOM requires soil nutrients like N-P-K-S to be tied up in the soil. Winter cover crops soak up excess soil nutrients and supply food to all the microbes in the soil during the winter months rather than microbes having to use up SOM reserves for nutrients. In a conventional tilled field, soil nutrients are quickly released as SOM is burned up and the microbes and soil organisms habitat are destroyed. In a no-till field, high levels of SOM are reserves of soil nutrients which are slowly released into the soils. Adding a living cover crop to a no-till field increases active organic matter (sugars and proteins) for the soil microbes. Soil microbes have two crops to feed on instead of one crop per year. Microbes thrive under no-till conditions and winter cover crops. Cover crops and manure can be used to feed soil microbes and recycle soil nutrients. As soil microbes decompose organic residues, they slowly release nutrients back into the soil for the winter cover crops or for the preceding crop. Cover crops prevent the nutrients from being lost through soil erosion, leaching, volatilization, or denitrification.

Summary

Microorganisms abound in the soil and are critical to decomposing organic residues and recycling soil nutrients. Bacteria are the smallest and most hardy microbe in the soil and can survive under harsh conditions like tillage. Bacteria are only 20–30% efficient at recycling carbon, have a high nitrogen content (3 to 10 carbon atoms to 1 nitrogen atom or 10 to 30% nitrogen), a lower carbon content, and a short life span. Carbon use efficiency is 40–55% for mycorrhizal fungi so they store and recycle more carbon (10:1 carbon to nitrogen ratio) and less nitrogen (10%) in their cells than bacteria. Fungi are more specialized but need a constant food source and grow better under no-till conditions.

Soil organic matter (SOM) is composed of the "living" (microorganisms), the "dead" (fresh residues), and the "very dead" (humus) fractions. Active SOM is composed of the fresh plant or animal material which is food for microbes and is composed of easily digested sugars and proteins. The passive SOM is resistant to decomposition by microbes (higher in lignin). Active SOM improves soil structure and holds plant available nutrients. Every 1% SOM contains 1,000 pounds of nitrogen, 100 pounds of phosphorus, 100 pounds of potassium, and 100 pounds of sulfur along with other essential plant nutrients. Tillage destroys SOM by oxidizing the SOM, allowing bacteria and other microbes to quickly decompose organic residues. Higher temperatures and moisture increase the destruction of SOM by increasing microbial populations in the soil. Organic residues with a low carbon to nitrogen (C:N) ratio (less than 20) are easily decomposed and nutrients are quickly released (4 to 8 weeks), while organic residue with a high C:N ratio (greater than 20) decompose slowly and the microbes will tie up soil nitrogen to decompose the residues. Protozoa and nematodes consume other microbes in the soil and release the nitrogen as ammonia, which becomes available to other microorganisms or is absorbed by plant roots.

Acknowledgment

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Related Publications

- Sustainable Crop Rotations with Cover Crops
- Using Cover Crops to Improve Soil and Water Quality
- Crop Rotations with Cover Crops
- The Biology of Soil Compaction
- Using Cover Crops to Convert to No-till
- The Role of Soil Bacteria
- The Role of Soil Fungus
- The Role of Soil Protozoa and Nematodes
- Homegrown Nitrogen

Caring for the Soil as a Living System

Mark Schonbeck
Virginia Association for Biological Farming Information Sheet

Number 2-06 05/15/06 http://www.vabf.org/pubs.php

Soil provides the basis of all plant, animal and human life on land. It consists of mineral matter (clay, silt, sand, gravel, stones), air- and water-filled pore spaces, organic matter (dead roots and other plant and animal remains, plus humus), and a great diversity of living organisms. In organic and sustainable cropping systems, the soil life is the engine of soil fertility and crop production, as well as the guardian of long term soil health.

Contents:

The Soil is a Living System

A living system consists of life forms, and the food, air, water, habitat and shelter they need to thrive, grow and reproduce. In the soil *organic matter* (replenished each season) becomes food; the soil's *structure* and network of *pore space* provide habitat, air and water; and *living vegetation* and *surface residues* offer shelter. Figure 1 shows approximate proportions of mineral matter, pore space and organic components in a good topsoil.

Sustainable growers tend the soil life as they would any other valuable farm livestock. Just as farmers make sure their cattle, sheep or poultry get regular food and water, and shelter from severe weather, they can keep the soil life well fed and protect it from erosion, compaction and temperature extremes.

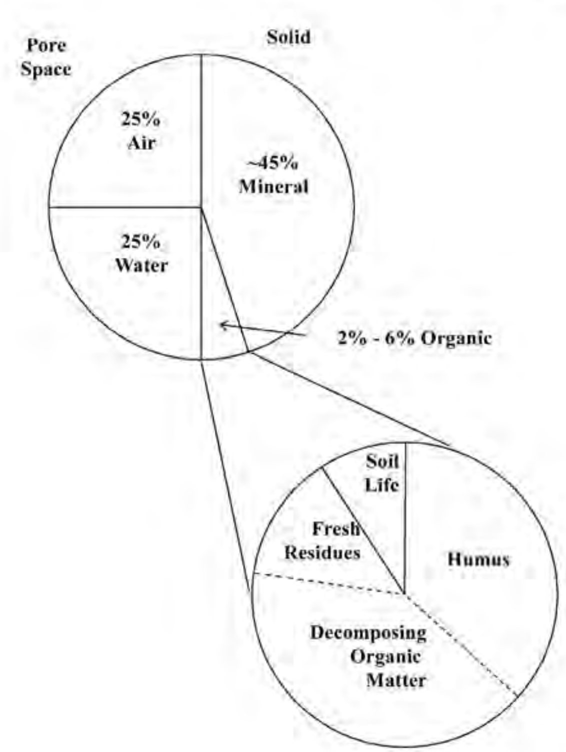

Figure 1. Approximate proportions of mineral matter, air and water-filled pore space, organic matter and living organisms in topsoil.

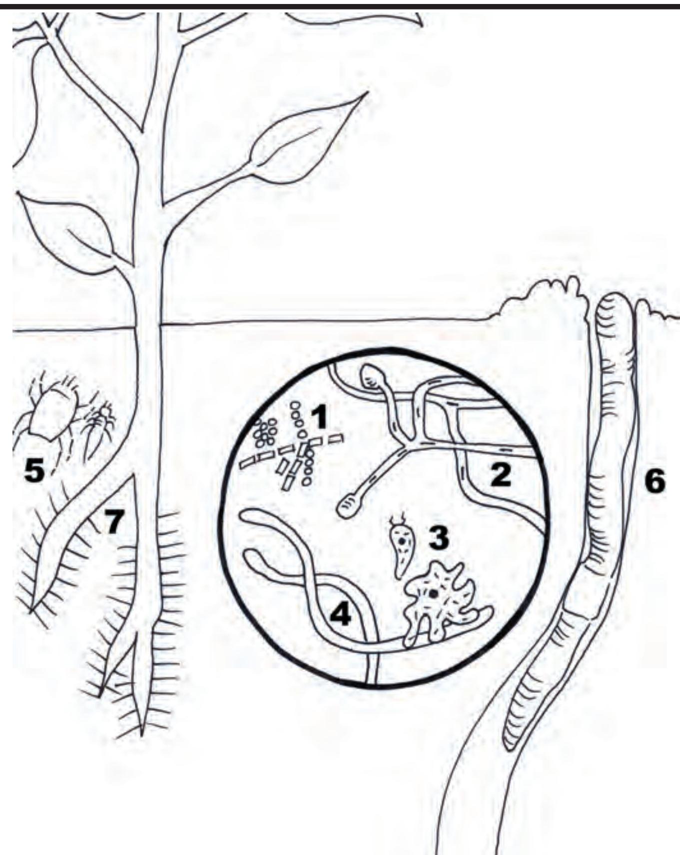

Figure 2. Main components of the soil life: (1) bacteria, (2) fungi, (3) protozoa, (4) nematodes, (5) mites, insects and other arthropods, (6) earthworms, and (7) plant roots.

One teaspoon of healthy agricultural topsoil may contain 100 million to one billion bacteria, several yards of fungal filaments, several thousand protozoa, and ten or twenty nematodes (tiny, simple worms) that together represent *thousands* of different species of microorganisms. In addition, a good soil may contain up to 100 insects, mites and other arthropods, and five to 30 earthworms per square foot, 1000-2000 lb (dry weight) of plant roots per acre, and some moles and other burrowing animals. Figure 2 shows main components of the soil food web.

This soil life is organized into a highly complex "food web." Bacteria and fungi feed on organic residues and plant root exudates; protozoa and nematodes feed on the bacteria and fungi; mites and insects feed on all of the above and on each other; and earthworms ingest soil and decomposing organic matter, absorbing nutrients released by microorganisms thereon. Some soil organisms also feed directly on plant roots, but in a healthy soil with good biodiversity, such pests are in the minority and pose little threat to vigorous plants.

In natural forest and prairie ecosystems, the action of the soil life feeding on each year's organic residues (fallen leaves, dung, dead plants and animals, etc) releases the nitrogen (N), phosphorus (P), potassium (K) and other nutrients needed for the next season's plant growth. In annual crop agriculture, crop harvest removes organic matter and nutrients from this cycle, while tillage and cultivation damage some components of the food web and accelerate the breakdown of soil organic matter. It is now widely recognized in both mainstream and alternative agriculture that the grower needs to replenish organic matter and soil life regularly, as well as mineral nutrients.

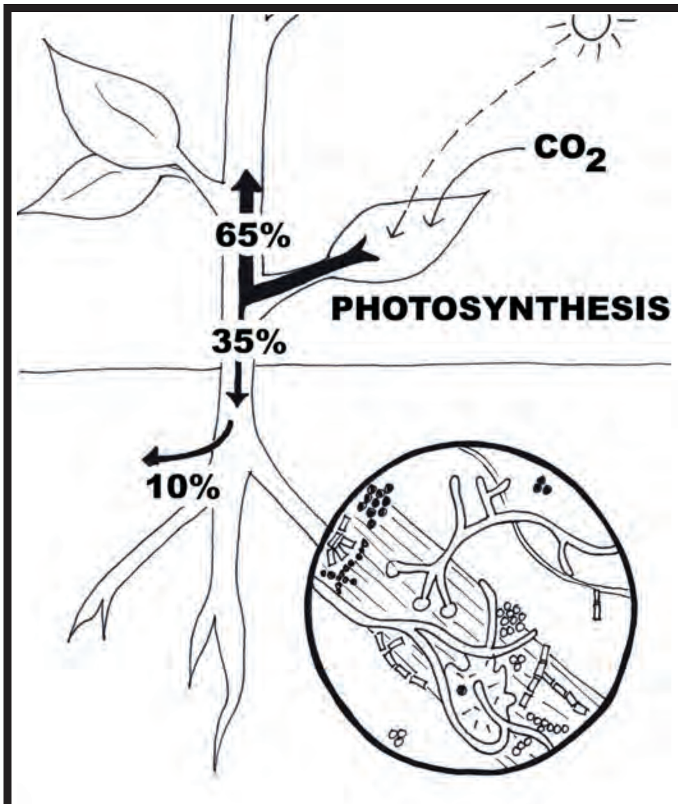

Figure 3. Plants release a significant portion of their annual photosynthetic product into the soil, supporting a vibrant microbial community in the root zone and forming a vital link between plant and soil.

Living plants are a vital part of the soil life

Living plants make a substantial contribution to soil organic matter, thereby linking soil and above-ground ecosystems. Some 25-50% of a plant's total annual photosynthate (sugars, amino acids, *etc.*, formed through photosynthesis) moves into the root system, and perhaps 10% is released into the soil as soluble *root exudates*. Root systems also slough off dead cells and fine roots throughout the season. These root deposits, which can amount to 1-2,000 lb per acre per year, support a thriving microbial community in the rhizosphere (the part of the soil adjacent to plant roots), with population densities 10-20 times that in the bulk soil. Figure 3 shows the plant-soil-life relationship.

Why would a plant "tithe" its energy to the soil in the form of root exudates? Certain organic acids and chelating agents in exudates help the plant absorb essential nutrients directly from insoluble minerals. Meanwhile, soil organisms thrive on the sugars, amino acids and other readily available food that comprise most of the exudates. The vast majority of these organisms are harmless, and *many are highly beneficial to the plant.* Some organisms enhance the plant's uptake of moisture and nutrients, while others protect the plant from diseases and other stresses. The proliferation of benign organisms in the rhizosphere crowds out and suppresses soil-borne pathogens (disease-causing microorganisms). Research findings now suggest that each plant species releases specific chemical signals that stimulate those organisms that are particularly beneficial to that plant.

One of the most important groups of soil fungi, the *mycorrhizae,* grow within plant root tissues and extend hyphae (filaments) some distance into the surrounding soil. Mycorrhizal symbioses expand several-fold the volume of soil from which plant roots can absorb moisture and nutrients, and strongly enhance uptake of P and trace minerals. About 80% of the world's plant species, including most food crops, form mycorrhizal associations, some investing 5-10% of their annual photosynthate in these beneficial fungi.

In some cases, root exudates will "wake up" pathogens that can harm the plant. This usually occurs when the plant is poorly adapted to the climate, season or soil type, when the plant has already been weakened by other stresses, or when the soil food web has been depleted through inadequate organic inputs. It may also occur when an *invasive exotic* pathogen is introduced in the absence of microbial natural enemies; sadly some forest trees are now threatened by such outbreaks.

Living plants also provide *shelter* for the soil surface. Bare soil is subject to intense heating and drying by direct sun, and to compaction and erosion under the impact of rainfall. After a few weeks' exposure, the top inch or so of soil may become a "dead zone," forming a surface crust that blocks aeration, absorption of rainfall and seedling emergence. A cover of living vegetation and/or organic mulch protects the biologically active top layers from desiccation, crusting and erosion.

More on the Benefits of Soil Life

Soil organisms consume fallen leaves, dung and other organic residues, converting them to *biomass* (more soil life), *active organic matter* (substances that can serve as food for other soil organisms), and *humus* (stable organic matter that contributes to the soil's long-term nutrient and moisture-holding capacities). *All* of these components, not just the humus, make up the Soil Organic Matter (SOM), and are vital to soil health. Cut off the influx of organic soil "food" and soil quality suffers within a couple of years, even though the humus level may not drop measurably until after decades of poor management.

In the initial phases of residue decomposition, soil bacteria and fungi capture and hold soluble nutrients like N so they do not leach into the groundwater. Protozoa, nematodes and other larger organisms feeding on the fungi and bacteria then release N, P, K and other nutrients – gradually, as the plant needs them. The constant activity of plant roots, bacteria, fungi and other soil life maintains an open, crumbly soil structure, enhances drainage and aeration, and reduces erosion.

Tired, worn-out soils are those in which the soil life is starving or is out of balance. The use of soluble fertilizers without organic inputs leaves the soil life nothing to live on. Soil fumigants, strong pesticides and anhydrous ammonia (a N fertilizer) kill soil organisms outright. Tillage aerates the soil, stimulates bacteria and accelerates the breakdown of organic matter. This releases crop nutrients and can enhance yields in the short run, but intensive tillage degrades soil quality in the long run.

The Sustainable Approach: Feed the Soil

In *sustainable agriculture* (including organic, biodynamic and ecological farming and gardening) the grower aims to *feed and protect the soil life,* so that the soil can support healthy crops and livestock. This is done through:

- cover cropping and green manuring
- organic mulches
- compost applications
- returning on-farm residues to the land
- crop rotation
- natural mineral or organic fertilizers as needed
- reducing intensity and frequency of tillage.

How much organic matter needs to be added each year? Here in the South, our warm humid climates promote rapid decomposition of SOM, perhaps 2,000-3,000 lb per acre per year. When fresh organic materials are added, only a fraction is converted into new soil organic matter, the rest being lost as carbon dioxide from the soil life respiration process. About 15-20% of the organic matter in fresh plant foliage, 30-40% for roots, 25-35% for manure, and 50% for compost remains as SOM at the end of one year. The annual loss of SOM might be replenished by growing a heavy cover crop, *or* by applying a 3-4 inch hay mulch, *or* 5-10 tons per acre of compost *or* 20 tons per acre fresh dairy manure. However, like humans and livestock, the soil life thrives best on a balanced and varied diet. Thus the best strategy is to add a *diversity* of organic inputs that *together* provide 5-10 tons/acre (225-450 lb per 1,000 sq ft) of organic matter annually. Note that this is on a dry weight basis; fresh manure may contain 25% organic matter (the rest is water); compost 25% (the rest is mineral matter and water); and dry hay 90%. A mature cover crop can add 3-6 tons organic matter per acre.

Cover cropping is the cornerstone of sustainable soil management in annual cropping systems, because cover crops feed the soil both while growing and after they are tilled in, mowed or frost-killed. They also prevent soil erosion, suppress weeds and harbor natural enemies of insect pests. Legume cover crops add N, without adding P or K. This can be advantageous, as intensive agriculture often leads to a buildup of soil P and K, but rarely N, since N surpluses leach away. For more on cover crops, see the information sheet #1-06*, Cover Cropping: On-Farm, Solar-Powered Soil Building.*

Organic mulches such as hay, straw, leaves or chipped brush simulate the natural process of autumn leaves or other plant residues falling on the ground and gradually decomposing in place. The mulch breaks the erosive force of raindrops, prevents surface crusting, and maintains a favorable environment for earthworms. Nitrogen-poor materials like straw or wood chips are less likely to tie up soil N when applied as mulch than when incorporated into the soil. Note that repeated heavy mulching, especially with hay, can cause soil K to build up to excessive levels. A cover crop, grown to the full bloom stage, then mowed or rolled to form mulch in place, does not add K in this way.

Compost is mainly an inoculant rather than a food source for soil life. A well-managed composting process speeds up the soil food web in the pile or windrow, consuming most of the readily-available "food" to generate a tremendous number and diversity of desirable soil microbes. A light application of high quality compost every few years – perhaps 1-3 tons/acre (45-135 lb per 1,000 sq. ft) helps to sustain the abundance and diversity of soil life.

In the early days of organic farming compost was recommended as *the* soil food of choice and gardeners were applying an inch or more annually. Because of the labor and other costs of making compost, such heavy applications may not be feasible at the farm scale. They can also lead to soil imbalances, especially if the compost is based partly on manure. Plants utilize N and P in a ratio of about 6 to 10 parts N to one part P, whereas the N:P ratio of manure is about 2. Applying enough compost to supply the crop's N needs will lead to a buildup of P and sometimes K. This can lead to P nutrient pollution of nearby bodies of water and cause crop nutrient imbalances that reduce quality or yield. Annual compost applications of 10-20 tons per acre (450-900 lb/1000 sq ft) can restore worn-out soils low in nutrients and soil life. Once soil P and K levels have reached optimal or high ranges, compost application should be reduced, and organic inputs provided through cover crops and crop residues.

Hot composting sanitizes certain materials such as manure and crop residues that may be infested with pests, pathogens or weed seeds. The USDA National Organic Standards require that manure be composted at high temperatures (>130°F) for at least 15 days if it is to be applied within 120 days of harvest of an organic food crop. If hot composting is not feasible, manure can be spread at 5-10 tons/acre (2-4 tons/acre for poultry litter) just before sowing a *cover* crop. The fertilized cover crop will grow extra biomass and hold most of the manure N against leaching. Note that when manure is produced on-farm as part of a fairly "closed" nutrient cycle, its application to fields is much less likely to create nutrient imbalances.

Crop rotation is an essential part of sustainable soil management and not only because it reduces pest and disease problems. Different crops make different demands on the soil, support different microbial communities in their rhizospheres, and have different root structures and depths. The more diverse a crop mix, the greater the diversity of soil life, and the less probability that detrimental soil organisms will dominate and damage one or more crops.

Developing a good crop rotation is as much an art as a science and is inherently *site specific*. Research has shown that many "rotation effects" and "companion plant" effects (both favorable and adverse) relate to the rhizosphere microflora as well as root exudate chemistry. For instance, in the Northeast, microbes that frequent the root zone of red clover seem to favor potato and hurt corn. However, soil microbial communities vary with region, climate and soil type, and this interaction might look different in our region. For the dedicated grower, careful observation and on-farm selection of crop seed for several generations can point the way to crop rotations and variety selection that take advantage of beneficial crop-microbe-soil interactions, as well as minimize unfavorable ones.

Natural mineral and organic fertilizers or soil amendments can play an important supporting role in a living soil. Just as individual people may require specific vitamin or mineral supplements to improve or maintain their health, most soils will need some supplementation. In particular, heavy-feeding, cool-season vegetables like broccoli, spinach or lettuce may need supplemental N in all but the most biologically active soils. A good soil test and proper interpretation will identify what fertilizers or amendments might be needed. For more on soil testing and amendments, see the information sheet, *How to Use a Soil Test.*

Till with care- the less the better! Judicious, soil-conserving tillage practices are critical for maintaining soil life and organic matter. This is especially true on sloping land, where conventional tillage practices can lead to the loss of 10-100 tons of topsoil annually. Such erosion also robs a disproportionately large fraction of the organic matter. Steeper slopes should be left in perennial cover such as pasture or orchard. Even in flat fields, simply converting from conventional tillage to no-till has led to net accretions of nearly 1000 lb SOM per acre per year in some southern US soils. SOM can increase a full percentage point in 20-30 years. More important, the *active organic matter* component, which is closely correlated with soil quality and productivity, rebounds faster (within a few years), in response to reduced tillage. *Continuous* no-till is not feasible in organic annual cropping systems in which herbicides cannot be used to control weeds. However, the intensity and frequency of tillage can often be reduced, and least-destructive implements can be used. Moldboard plowing, which inverts and buries the biologically-active surface layer, is particularly destructive to SOM and soil life. Repeated disking or rotary tillage can pulverize soil crumbs, kill off fungi and create hardpan. Chisel plowing provides deep tillage and relieves hardpan without soil inversion, and the new rotary and reciprocating spaders can break hardpan, incorporate residues and cover crops, and leave a good seedbed without seriously degrading soil structure. As soil structure improves in response to better care of the soil life, less and less tillage will be needed to form a seedbed.

Tillage does the least harm when the soil is moderately moist, neither dry and dusty nor wet enough to compact or stick together under the impact of the tillage implement. Subsoiling or chisel plowing should be done to a depth just an inch or so below the hardpan, and when the soil is dry enough that the shank fractures the hardpan rather than simply carving through it. Shallow (≤1 inch) cultivation is useful for breaking a surface crust while knocking out small weeds and leaves most of the soil profile undisturbed. When weed pressure or other circumstances necessitate intense or repeated tillage, growing vigorous cover crops can help minimize net losses in SOM.

Soil "Metabolism" and Site-Specific Soil Care

Each soil is unique and requires a site specific approach for optimal results. Like people, some soils have a fast metabolism and others have a slower metabolism. The warmer the climate and the sandier and faster-draining the soil, the faster the soil life consumes organic matter, and the lower the "steady state" SOM levels. Thus in a sandy loam with 75-80% sand, a 2% SOM level on a soil test might reflect a healthy, well-fed soil food web and excellent soil management. On the other hand, the soil life in a clay-loam in the cooler Appalachian region works much more slowly on added organic residues, and a 2% SOM level might indicate a virtually dead soil. Under good management, this cool, heavy soil should eventually reach 5% SOM, which will in itself improve drainage and aeration.

Soil type can also inform tillage decisions. Tillage acts as a stimulant to the soil life, much like coffee for a person. Reducing tillage to the absolute minimum on the Tidewater sandy loam will help slow the burn-up of organic matter and help match the release of nutrients to crop need. In contrast, the Appalachian clay loam may benefit from appropriate non-inversion tillage prior to crop planting, in order to aerate the soil, stimulate soil life and release nutrients in a more timely fashion for crop production. No-till plantings in cool, heavy soils often cannot give optimum yields without applying soluble N. Over time, farmers learn from experience what management practices work best for their particular soils.

Resources

ATTRA offers several thorough information bulletins, including Sustainable Soil Management, Drought-Resistant Soils, Sustainable Management of Soil-borne Diseases, Compost Tea and other relevant topics. Visit *www.attra.ncat.org/soils.html* to view a listing and download bulletins.

Magdoff & Van Es, 2000. *Building Soils for Better Crops*, 2nd ed. Sustainable Agriculture Network, USDA, 240 pp. Available through *www.sare.org/publications/index.html*.

Soil Biology Primer – USDA-Natural Resources Conservation Service, Soil Quality Institute. *www.statlab.iastate.edu/survey/SQI/sqihome.shtml.*

Soil Quality – Agronomy Technical Notes. A series of information sheets on practical methods for enhancing soil life, organic matter and soil quality published by the Natural Resources Conservation Service's Soil Quality Institute, 411 S. Donahue Dr., Auburn, AL 36832, tel. 334-844-4741, ext. 177; web *http://soils.usda.gov/sqi*.

Fred Magdoff & Ray R. Weil, 2004. *Soil Organic Matter in Sustainable Agriculture*. CRC Press, 2004, 398 pp.

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THE OHIO STATE UNIVERSITY EXTENSION

FACT SHEET

Agriculture and Natural Resources

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AEX-540-09

Using Cover Crops to Convert to No-till

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No-till versus Tillage

In the Midwest, about three-fourths of all soybeans and wheat are planted without prior tillage. But before corn is planted at least three-fourths of the fields are tilled in the fall and possibly tilled again in the spring. Farmers are tilling ahead of corn planting because they perceive a yield increase with tillage that is more than enough to cover the added direct costs for machinery, fuel, and labor. Typically, soybeans are no-tilled into corn stalks followed by soybean residue being tilled for corn planting the next year. No-tilling one year (for soybeans), then tilling the next (for corn), is not a true no-till system.

In many situations, corn yields drop slightly after switching to no-till. In Ohio, 10–20% of corn acres are no-tilled. So the question becomes, Why does this occur? Since corn is a grass, it requires more nutrients (especially nitrogen) and water and corn responds well to tillage. Farmers typically see a 5–10% bushel yield decrease for the first 5–7 years after they convert from conventional tilled to no-till. The corn crop benefits from tilled soils due to the release of nutrients from soil organic matter. Tilling the soil injects oxygen into the soil, which stimulates bacteria and other microbes to decompose the organic residues and releases nutrients. Every 1% soil organic matter holds 1,000 pounds of nitrogen. However, continuous tillage oxidizes or burns up soil organic matter and soil productivity declines with time. Thus, tillage results in poor soil structure and declining soil productivity.

Long-term research reveals that 7–9 years of continuous no-till produces higher yields than conventional tilled fields because it takes 7–9 years to improve soil health by getting the microbes and soil fauna back into balance, and start to restore the nutrients lost by tillage. In those transition years, the soil is converting and storing more nitrogen as microbe numbers and soil organic matter levels increase in the soil. For the first several years after converting to no-till, there is competition for nitrogen as soil productivity increases and more nitrogen is stored in the soil in the form of organic matter and humus. See OSU Extension fact sheet Understanding Soil Ecology and Nutrient Recycling.

Cover crops have the ability to "jump-start" no-till, perhaps eliminating any yield decrease. Cover crops can be an important part of a continuous no-till system designed to maintain short-term yields and eventually increase corn yields in the long run.

Cover crops recycle nitrogen in the soil, help to build soil organic matter, and improve soil structure and improve water infiltration to improve no-till corn yields. Long-term cover crops can boost yields while improving soil quality and providing environmental and economic benefits. Growing cover crops is helping farmers adapt faster to a continuous no-till system, one that provides long-term economic and environmental benefits that are impossible to obtain by no-tilling one year at a time.

Ecosystem Functionality

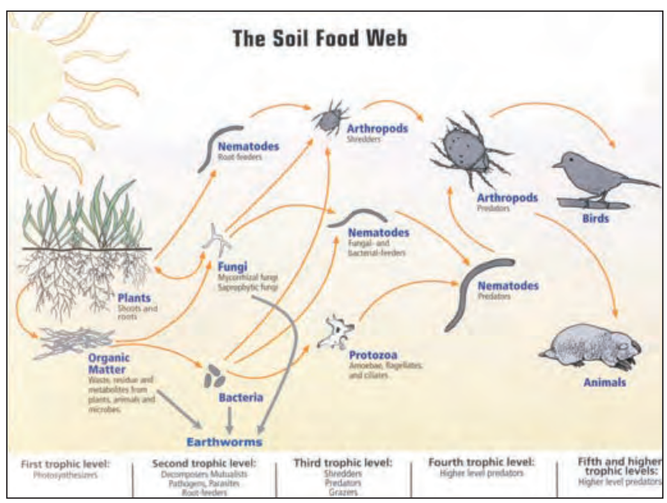
Our agricultural landscape is only green for about 6 months during the year with no living cover for the other 6 months. Corn and soybeans are planted in the spring and harvested in the fall. Fall tillage prepares the seed bed for the following crop but leaves the soil exposed and fallow. The result is a soil surface devoid of plant life for 6 months and a decrease in "ecosystem functionality." In a typical corn-soybean rotation, there are active living roots only a third of the time (Magdoff and van Es, 2001). Typically there are 1,000–2,000 times more microbes (especially bacteria and fungus) associated with living roots because the roots provide active carbon and exudates to feed the microbes (Schaetzl and Anderson, 2006).

Ecosystem functionality means that an ecosystem can sustain processes and be resilient enough to return to its previous state after environmental disturbance. Functionality depends on the quantity and quality of a system's biodiversity. An important characteristic of ecosystem functionality is that it develops and responds dynamically to constantly occurring environmental changes. Tillage is a constant disrupter and biodiversity in the soil decreases as tillage increases.

Tillage releases carbon to the atmosphere by oxidizing the soil organic (carbon based) residues and in the process releases nitrogen. Nitrate leaching typically occurs after the crop is harvested in the fall, winter, and early spring months because after the microbes release the nutrients, there are no live plants to recycle the excess nutrients. Tillage also increases soil erosion and phosphorus losses (phosphorus attaches to clay soil particles) to surface water. Excess nitrogen and phosphorus in the water cause hypoxia and eutrophication in surface waters. Ecosystem functionality decreases because the soil biodiversity decreases and there is less recycling of nutrients in the soil. That explains why the nitrogen use efficiency for commercial N and P fertilizer is only 30–40% for N and 50% for P. By improving ecosystem functionality, farmers can increase their N and P nutrient use efficiency, decrease their fertilizer bill, and improve the environment by decreasing N and P losses to surface water.

In the last hundred years, tillage has decreased soil organic levels by 60–70% with 30–40% soil organic carbon stocks remaining. Carbon stocks (30–40%) correlate directly with nitrogen use efficiency (30–40%) and the two are directly related to each other. To increase nitrogen and other nutrients in the soil, farmers need to increase carbon or organic matter. Carbon is the glue that binds the soil, stores nutrients, and keeps nutrients recycling.

Ecosystem functionality decreases as the soil carbon content decreases because carbon is the food for microbes and the storehouse for many nutrients. Most soil nitrogen (>90%) and available phosphorus (50–75%) is stored in the organic form. Nitrogen use efficiency for corn is directly related to the amount of soil organic carbon in the soil. The soil carbon holding capacity is 2.5 times the amount of carbon dioxide in the atmosphere, so the soil has a tremendous ability to store carbon. Ultimately,



Ecosystem functionality is dependent on a healthy soil food web. Each species has a certain role and function in the soil.

a loss in soil ecosystem functionality reduces the quality of life for the farmer, land owners, our rural communities, and our society.

Continuous Living Cover and No-till

An agricultural system that combines a continuous living cover (cover crops) with continuous long-term no-till is a system that more closely mimics natural systems and should restore ecosystem functionality. A thick layer of plant residue on the soil surface protects the soil from the impact of rain drops, moderates soil temperatures, and conserves soil moisture. Soil microorganisms and plants together produce polysaccharides, and glomalin (a glycoprotein) which acts like glue to bind soil particles and improve soil structure. Living roots increase pore space for increased water infiltration, soil permeability, and increased water holding capacity and recycle soil nutrients (nitrogen and phosphorus) in the soil profile.

In natural systems, the land is not extensively tilled and a continuous living cover protects the soil from rain drop impact (less erosion). By growing a cover crop in the winter, carbon inputs are added to the soil, keeping nutrients recycling within the system. Nitrogen is directly linked to carbon so less carbon losses means more nitrogen stays in the soil rather than being lost through leaching or runoff. Soil nutrients (N and P) are recycled within the natural system. Plant roots and soil residues protect the soil and keep the soil from eroding and reduce P losses resulting in less hypoxia and eutrophication. Microbial diversity and microbe numbers increase with continuous living covers so that pests (disease, insects, and weeds) can be more effectively moderated. The solution lies in changing agricultural practices to promote greater nutrient efficiency to recycle carbon, nitrogen, and phosphorus in the soil. Improved soil productivity, soil structure, and nutrient efficiency should increase crop yields and farmer profitability.

No-till corn planted into cowpeas as a cover crop with no additional commercial N fertilizer. Photo by Dr. Rafiq Islam.

Nitrogen Recycling

Legume cover crops (cowpeas, Austrian winter pea, etc.) can provide nitrogen to the following crop. Legume cover crops fix nitrogen from the air, adding up to 50–150 pounds per acre of this essential nutrient. Non-legume cover crops recycle leftover nitrogen from the soil, storing it in roots and aboveground plant material, where a portion will be available to the following crop. Every pound of nitrogen stored is a pound of nitrogen prevented from leaching out of the top soil into streams (see OSU Extension fact sheet on Homegrown Nitrogen and Crop Rotations with Cover Crops).

Cover crops can replace nitrogen fertilizer, but not in every situation. After cereal rye, there may not be enough early nitrogen available for the new crop and after a legume, the N will likely not be available until later in the growing season depending upon when the crop decomposes. It all depends upon the carbon to nitrogen ratio.

A C:N ratio less then 20 allows the organic materials to decompose quickly while a C:N ratio greater than 30 requires additional nitrogen and slows down decomposition. Microbes will tie up soil nitrogen if a high carbon-based material with low nitrogen content (cereal rye or wheat straw) is added to the soil. Eventually the soil nitrogen is released but in the short-term the nitrogen is tied up. A low C:N ratio means more nitrogen is available quickly for microbes and plants to convert nitrogen to amino acids and protein.

Microbes generally take up nitrogen faster than plants, so if nitrogen is limiting, the plant will suffer. In no-till corn, corn is sometimes yellow from a lack of nitrogen because as the soil carbon content is increasing, the microbes are using the limited nitrogen stocks before the corn plant. A typical soil

C:N ratio is 10–12 so nitrogen is available to plant roots. If the soil C:N ratio is too high, adding nitrogen to the soil will allow the microbes to decompose the carbon residues and will decrease the C:N ratio and more nitrogen will become available to the plant.

For cereal rye and annual ryegrass before corn, plan to kill it 3–4 weeks before planting (when it is young and lush and the C:N ratio is lower). If it cannot be killed until about 2 weeks before planting, apply nitrogen (as liquid fertilizer or dry fertilizer). Cereal rye and annual ryegrass provide good rooting and soil structure and absorb nitrogen, which can be recycled for the following corn crop but depending upon the C:N ratio, may tie up nitrogen short-term, hurting corn yields.

Cowpeas may supply 120–150 pounds of N to no-till corn. No-till corn (background) planted into cowpeas with no additional commercial fertilizer. Note dark green color indicating good N fertilization. Cowpeas (foreground) drilled into wheat stubble 7 days after planting. Photo by Dr. Rafiq Islam.

Cereal ryegrass rolled before planting soybeans. Some farmers drill soybeans directly into the cereal rye then spray the cereal rye after the soybeans emerge. The cereal rye helps to control weeds and hold soil moisture going into the summer.

Cereal rye or annual ryegrass management is different for soybeans. Soybeans can be successfully no-till drilled into a standing cereal rye cover, even 7 feet tall. The cereal rye gets flattened, helping to smother potential weed growth, and is fairly easy to kill with herbicides (Roundup®) after planting. Annual ryegrass will reach 3–4 feet tall but should not be allowed to go to seed. Since soybeans are legumes and make their own nitrogen, the carbon content or C:N ratio of cereal rye and annual ryegrass does not hurt the soybean growth or yield.

No-till corn generates 14% less CO_2 losses than intensive tillage. Among the advantages are: less fuel used; soil quality and structure improves; better drainage, which can lead to earlier planting. Potential disadvantages include more weeds, more herbicides (to initially kill the cover crops), slower soil drying in spring at least initially (until soils are better aerated) , and more N required in the transitional years until soil compaction is reduced and or drainage is improved. The nitrogen may be provided, at least in part, by manure or cover crops.

Reduced Soil Erosion and Phosphorus Retention

Using a continuous living cover with no-till greatly reduces soil erosion and the loss of phosphorus with runoff. Remember that 50–75% of the available P in soil is organic and our P efficiency is only about 50% with tillage. Since the majority of the phosphorus (P) in the soil is attached to clay particles and organic matter, protecting the soil from rain drops results in less sediment erosion and keeps the P on the soil, rather than as runoff to surface water. Over 90% of P runoff is associated with phosphorus attached to the soil when soil phosphorus levels are below 100 pounds per acre Bray P1. Phosphorus in the soil is quickly tied up by clay particles so tillage incorporates P into the soil and binds P quickly.

In no-till, as the crop residues decompose, they release soluble P, which can flow to surface waters. Growing a living crop with no-till or adding a cover crop allows the soluble P to be absorbed and recycled back into the soil system.

In long-term no-till systems with a continuous living cover (cover crops), P is efficiently recycled on the soil surface so less P fertilizer is needed. A continuous living cover protects the soil from soil erosion, where a majority of the P is lost. With tillage, the P is incorporated into the soil and binds to the soil, but since the soil is not protected, soil erosion may increase sediment and P losses to surface water. When soil erodes, the nutrient-rich portion or the organic matter is the first portion to erode off in sediment because it is less dense than soil particles, floats, and can easily be washed away from the soil surface into surface water.

Soil Temperature

Living cover crops can significantly alter soil temperatures. Cover crops decreased the amplitude of day and night temperatures more than average temperatures resulting in less variability. Cover crop mulches protect the soil from cold nights and slow down cooling. This may be a benefit in hot regions, but may slow growth in cooler regions. Winter cover crops moderate temperatures in the winter. Standing crops have higher soil temperatures than flat crops. Row cleaners help manage residues and improve soil temperatures in no-till fields. Corn responds to warmer soil temperatures so strip tilling in a 10 inch band by moving the top soil residue may increase stand establishment and corn growth initially when converting from conventional tillage to no-till.

No-till soybeans drilled into a cover crop. Cereal rye and annual ryegrass used as a grass cover crops before soybeans, a legume grain crop. Photo by Dr. João Moraes Sá.

Long-term no-till farmers who use cover crops say that their soils are not cold. There are three reasons why this occurs. **First**, in the transition from conventional tillage to no-till, soils tend to be compacted, keeping the soil wet and saturated. Water holds the heat and cold longer than air, which acts like an insulation. Thus, cold soils tend to be wet and insulated from the atmosphere by residue on the soil surface. Cover crops in a no-till rotation allow rainfall and precipitation to infiltrate the soil (soils are more porous) and allow more air into the soil to warm up the soil faster. Grass cover crops can typically penetrate 12 inches of soil compaction per year, so it may take several years to remove soil compaction that is several feet deep.

Second, in long-term no-till with cover crops, as organic residues are added to the soil surface, the soil color changes from light yellow and brown to dark brown and black as organic residues decompose. Dark brown and black organic residues absorb sunlight and heat, warming the soil. This process may take several years to occur.

Third, as even more organic residues accumulate on the soil surface, the intensity of the biologic activity on the soil surface increases. Biologically active organic matter like compost piles give off heat as the microbial decomposition intensifies, warming the soil. In order for this last sequence to occur, a thick layer of residue needs to accumulate on the soil surface. Long-term no-tillers and no-till farmers using cover crops say that the improved soil porosity and dark organic residues promote soil warming.

Cold versus Warm No-till Soils

1. Compaction and poor drainage create cold soils because water holds both the heat and cold more than air. Cover crops improve drainage and aeration in no-till soil so they warm up faster in the spring.
2. Surface residue decomposes, turning black, and absorbs heat.
3. Thick surface residue increases microbial activity and creates heat, like in the center of a compost pile.

Controlled Traffic and Compaction

Soil compaction is a biological problem. Surface and subsoil tillage may physically break up hard pans and soil compaction temporarily but they are not a permanent fix. Good soil structure requires the production of glomalin, formed from polysaccharides produced by plants and fungus in the soil. The plant roots provide the sugar and the fungi provide the protein to form glomalin, a glycoprotein.

Glomalin coats microaggregate soil particles, forming macroaggregates, which improves soil structure and allow soil air and water to infiltrate and move through the soil. Tillage destroys macroaggregates by oxidizing the glomalin. Both cover crops and fungus microorganisms are needed to improve soil structure and decrease long-term soil compaction in the soil. (See the OSU Extension fact sheet: "The Biology of Soil Compaction.")

No-till corn (either in rotation or continuous) offers an opportunity for controlled traffic to manage compaction and provide other savings. Using auto-steering to maintain exact traffic patterns means that earlier planting and more timely harvest are possible because tracks are firm, resulting in higher grain yields. Precise steering means no overlap, which reduces costs of all inputs, including fuel and labor. Using auto-steering with a cover crop and no-till in a controlled system offers the opportunity to manage soil compaction so that it does not hurt crop yields.

Water Infiltration

As a plant grows, the roots create channels and fissures in the soil called macropores. These macropores allow air and water to infiltrate and move in the soil. These macropores also allow water to be stored. A pound of soil organic matter has the ability to hold 18–20 pounds of water. The organic residues stabilize the soil and hold soil moisture. A bare soil that has been tilled has the ability to hold 1.5–1.7 inches of water, while a continuously vegetated soil has the ability to hold 4.2–4.5 inches of water. Organic matter improves water infiltration, soil structure, and macropores in the soil. Living plants, plant roots, organic matter, and the polysaccharides in the soil (glomalin) stabilize the soil and allow the soil to retain more water than a tilled soil.

Cover crops produce more vegetative biomass than volunteer plants, transpire water, increase water infiltration, and decrease surface runoff and runoff velocity. If the velocity of runoff water is doubled in a stream, the carrying capacity of water or the stream competence to transport soil sediment and nutrients increases by a factor of 2^6 or 64 times. So 64 times more sediment and nutrients are lost with moving water when the velocity is doubled (Walker et al., 2006). Cover crops protect soil aggregates from the impact of rain drops by reducing soil aggregate breakdown. By slowing down wind speeds at ground level and decreasing the velocity of water in runoff, cover crops greatly reduce wind and water erosion.

Cover crops decrease soil erosion by 90%, decrease sediment transport by 75%, reduce pathogen loads by 60%, and reduce nutrient and pesticide loads by 50% to our streams, rivers, and lakes. As the price of fuel and fertilizer increases, planting cover crops becomes more and more economical as a way to build SOM and store and recycle nutrients in the soil. See the OSU Extension fact sheet on Using Cover Crops to Improve Soil and Water Quality.

Summary

Agricultural systems that mimic the natural world tend to be more efficient, sustainable, and profitable. Using a continuous long-term no-till system with cover crops or a continuous living cover is an agricultural system that closely mimics the natural world and restores ecosystem functionality. In no-till, a thick layer of residue protects the soil from the impact of raindrops and reduces soil erosion. Soil temperatures are moderated by this residue and soil moisture is retained in the soil profile. Water infiltration is improved and runoff is minimized. Soil nutrients are efficiently stored and recycled in the soil by growing plants or cover crops, allowing carbon to be recycled in the soil and storing nitrogen and phosphorus. Soil pests like weeds, insects, and diseases are controlled because there is a biological diversity, which generally prevents or moderates large increases in one species over another. Growing a continuously living cover with no-till promotes healthy growing crops and reduces the problems

Making No-till Corn Successful

No-till corn production has struggled to be successful in the Midwestern United States. No-till farmers say it takes 7–9 years to transition from conventional farming to long-term no-till. Using a cover crop with continuous long-term no-till shortens the time period to 2–4 years. No-till corn yields are typically reduced 10–20% during those transition years.

This occurs for several reasons. First, initially fewer nutrients are being released from the residues deposited on the soil surface. Tillage allows surface residues to decompose faster, releasing nutrients, but it also destroys organic matter, resulting in less storage of soil nutrients.

Second, in biologically active soils, the microbial biomass is increasing in size and population, accumulating N as amino acids and proteins and P as DNA in microbes. This initially deprives no-till corn of nitrogen and soil nutrients until the soil system becomes stable.

Third, the soil is building humus organic matter, which requires N to decompose and stabilize the organic molecule. Every 1% SOM requires 1,000 pounds of N, so if the N is being tied up and N is not available, the soil microbes will utilize N before the corn. Fourth, soil compaction from the previous tillage causes denitrification from saturated/water-logged fields, losing 40–60% of the available N in the soil.

So to reverse this process, first cover crops are grown to reduce soil compaction and improve the recycling of C and N in the soil. Second, as the microbial and humus organic matter levels build up, N and P are more efficiently recycled in the soil to the corn and no-till corn yields increase, outperforming conventional tilled soils. Third, as water infiltration increases and soils are better aerated, denitrification and N losses decrease, increasing the storage and recycling of N in crop residues and organic matter (humus) and resulting in more soil nutrients (N, P, and S) for the corn crop. See OSU Extension fact sheet Understanding Soil Ecology and Nutrient Recycling.

Reasons Why No-till Corn Struggles

1. Surface residue ties up nutrients and slows down decomposition and release of nutrients.
2. Soil microbes tie up soil nutrients, especially N.
3. Long-term soil organic matter ties up nutrients, especially N.
4. Compaction and poor drainage causes denitrification and loss of N.
5. Cold wet soils limit germination and planting.

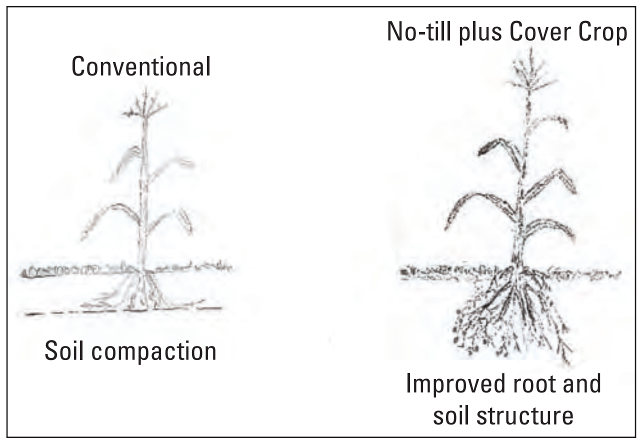


Diagram by James J. Hoorman. Illustrated by Danita Lazenby

Successful No-till Plus Cover Crops

1. Reduces soil compaction.
2. Improves C, N, P recycling.
3. Reduced N Losses from denitrification.
4. Increased nutrient storage in soil from increased SOM

most farmers have in growing crops with tillage (hard soil, cloddy soils, soil compaction, runoff, soil erosion, nutrient losses, annual weeds, insects, soil diseases). Tillage creates problems with soil compaction, water infiltration, soil structure, and nutrient recycling.

However, converting to no-till requires a transition period because the biological diversity has been diminished with tillage. Natural systems are fragile and once they have been disturbed it takes time to restore the ecosystem functionality. As the carbon is decomposed and released to the atmosphere, the capacity to store nutrients in the soil is diminished. The fastest way to build soil organic matter levels is to grow plants continuously using long-term no-till so that the residues are not decomposed. Continuous no-till plus a cover crop mimics natural cycles and promotes nutrient recycling and improved soil structure to improve crop production.

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Related OSU Extension Fact Sheets

- Crop Rotations with Cover Crops
- Understanding Soil Ecology and Nutrient Recycling
- Homegrown Nitrogen
- The Biology of Soil Compaction
- Using Cover Crops to Improve Soil and Water Quality

RODALE INSTITUTE™

COVER CROPS AND NO-TILL MANAGEMENT FOR ORGANIC SYSTEMS

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Why is it important to reduce tillage?

No-till practices were first introduced as a soil conservation tool and to decrease labor requirements and fuel use.[8, 26] Numerous studies have shown that soil is more protected from erosion and run-off in no-till systems[10, 18, 25, 31] and that yields in no-till systems can be as good or better than with conventional tillage.[6, 7, 16, 29] Soil carbon[2, 11, 30] and other soil quality parameters (aggregate stability, microbial activity, earthworm populations) can increase significantly after switching from conventional tillage to no-till.[16] Potential disadvantages of no-till are compaction, flooding or poor drainage, delays in planting because fields are too wet or too cold, and carryover of diseases or pests in crop residue.

In conventional ('standard') no-till systems, cover crops and weeds are usually controlled with herbicides rather than by tillage or cultivation. This increased dependence on herbicides[6] is often considered unsustainable, possibly leading to herbicide resistance in certain weeds and increased leaching of pesticides into groundwater due to higher infiltration rates in no-till systems.[15, 20, 25] In organic production systems, herbicide resistance and pesticide leaching are usually not a concern; instead, reducing tillage on an organic farm is of interest to reduce fuel and labor inputs and to improve soil and water quality.

How no-till works in an organic system

'Standard' no-till with herbicides is not an option in organic systems. In order to reduce frequency or intensity of tillage in organic systems, many farmers are exploring the option of terminating a cover crop mechanically by mowing, undercutting or rolling instead of plowing. The main crop is then seeded or transplanted into the terminated cover crop without using tillage. In this type of system, no-till planting is not continuously used for each crop but only for some of the main crops in the rotation (generally for crops that would require cultivation like corn, soybeans or vegetables). The success of this system very much depends on a well established cover crop that has dense, weed-free stands and produces large amounts of biomass for rolling or mowing. This is best achieved through timely planting of the cover crop into a clean seed bed created with tillage.

Cover crops and their many services

- prevent soil erosion by wind and/or water[12]
- increase yields, especially if legumes are used[17]
- enhance soil organic matter, aggregation and nitrogen storage[12, 23]
- reduce nitrate leaching
- conserve water resources[13, 28]
- reduce insect and pathogen damage[9, 19]
- compete with weeds
- fight compaction, soil crusting, increase aeration
- provide nutrients (for plants and microbes)

While plowing incorporates the cover crop into the soil, leaving the soil bare as a result, mowing, undercutting, and rolling all keep the cover crop on the soil surface to act as a weed suppressing and moisture conserving mulch. Flail mowing is usually the preferred method of cover crop mowing. It cuts low (right above ground level) and leaves an even layer of residue. Undercutting terminates a cover crop with sweeps or blades that travel just below the soil surface, cutting the plants below the crowns. Rolling is performed using a rolling drum with blunted blades that terminate the cover crop by rolling it into a mat without cutting the stems. Both undercutting and rolling keep the plants more or less intact and in place, thereby reducing decomposition rates and increasing the time the mulch stays on the soil surface and works to suppress weeds. Mowing chops the plant biomass into small pieces, increasing the rate at which the cover crop breaks down. In this publication we will focus on rolled cover crops.


Rolling rye and planting soybeans

Much of the interest in mechanical termination of cover crops, especially in the roller-crimper, comes from organic producers. However it can also be used in conventional systems. Some studies have shown that the roller-crimper in combination with a burndown herbicide, such as glyphosate, can both increase the effectiveness of cover crop control and reduce the rate of herbicides needed to kill the cover crop.[1, 4]


Rolling hairy vetch and planting corn

Field trials examining the effectiveness of the roller as a mechanical termination technique show promising results. Cover crop rollers can successfully terminate annual crops such as cereal grains (rye, wheat, oats, and barley) and annual legumes (hairy vetch, winter pea and crimson clover) without the use of any herbicides.[1, 21, 22] Rollers are not effective on perennials because they can't be killed by rolling and will continue to grow and compete with the main crop. In order to use the roller effectively, the annual cover crop needs to have switched from the vegetative to the reproductive stage - which means it needs to be in the flowering or anthesis stage (but before it has produced viable seed). If a cover crop is rolled too early, it will not die but continue to grow and compete with the crop that was planted into the rolled cover crop. In addition, if rolled too soon, the cover crop will most likely produce seed, turning into maybe the worst weed in the field. Recognizing the right (perfect) time for rolling may be the biggest challenge with this system, especially if it requires extra patience because you have to delay the planting date of the cash crop.

An advantage of the roller is the fairly small amount of energy and horse power required to operate it. Fuel needed for the roller is similar to a cultipacker and ten times less than the energy required for mowing.[14] The biggest energy savings, however, result from the reduced number of field operations: In a tilled organic system up to 10 field passes may be required from cover crop termination to harvesting of the main crop (plowing, disking, packing, planting, and several cultivations for weed control), whereas the no-till roller-crimper system can take as few as 2 passes (rolling+planting and harvesting).


Winter rye at anthesis, ready for rolling

Yield results and weed suppression for the roller-crimper system are also promising. In a field trial in Illinois, no-till soybeans grown after rye termination with a roller achieved similar yields to those in a chemically terminated cover crop while reducing residual weed biomass.[5] In another trial conducted in North Carolina soybeans were no-till planted into a rolled or flail mowed rye cover crop. Both treatments controlled weeds in the soybeans sufficiently (no herbicides were used) and yields were the same as in a weed-free treatment, as long as dry rye biomass was high (>9,000 lbs/a).[27]

Benefits and challenges of organic no-till systems

Benefits

- Reduces number of tractor passes over the field (saves time, fuel, and money)
- Keeps the soil covered to reduce erosion and weed growth
- Cover crop mat retains moisture and cools soil in mid-summer
- Eliminates herbicide use
- Provides a source of nitrogen to the cash crop (if leguminous cover crops are used)

Potential Challenges

- Nitrogen tie-up (when using crops with high C:N ratio, for example small grains)
- Can keep soil too cool in the spring
- Cover crop may use up a lot of water reserves
- Requires well-timed rolling and may result in later planting
- Heavy cover crop mat may pose a problem for the planter
- May provide habitat for plant-damaging pests
- Can allow weed growth if the cover crop stand is poor

Developing a rotation

For organic no-till to work, you will probably need to re-think your rotation. Cover crops are already a common feature in organic rotations, but they are even more important if that rotation includes organic no-till. You need to first identify the main reason for planting the cover crop and then determine which cover crop best fulfills that criteria and where it can fit into the rotation. Typical planting and termination dates of the chosen cover crop have to be coordinated with the planting and harvesting dates of the cash crop to ensure a wide enough growth window for both crops. As mentioned before, the success of this system very much depends on how well the cover crop is established. For example, if the cover crop is planted too late because the previous crop in the rotation is harvested late, there may not be enough time for the cover crop to produce enough biomass suitable for rolling. Trying to save time or money by either skipping steps in seed bed preparation or by reducing the cover crop seeding rate will also lead to less than ideal results.

Selection of cover crops suitable for rolling

Cover crop	Type	Hardiness °F	Seeding rate lbs/acre	Biomass range tons/acre	N fixed lbs/acre	Stage for rolling
Legumes						
Crimson clover	Winter annual	0-10	9-40	1.5-3	70-130	Flowering
Hairy vetch	Winter annual	-10	20-40	1-3	80-250	Full bloom
Fava bean	Summer annual	20	80-170	1-2.5	70-220	Flowering
Field peas	Winter annual	10-20	70-120	1-2.5	170-190	Flowering
Soybean	Summer annual	NFT	60-120	1.5-4		any time
Non-legumes						
Buckwheat	Summer annual	NFT	35-134	1-1.5	N/A	Flowering
Winter barley	Winter annual	0	70-120	1.5-5	N/A	Anthesis
Spring barley	Summer annual	15	50-125	1.5-4	N/A	Anthesis
Spring oats	Summer annual	15-20	50-100	1.5-4	N/A	Milk stage
Winter rye	Winter annual	-40	60-200	2-5	N/A	Anthesis
Winter wheat	Winter annual	-25	120-160	1.5-3.5	N/A	Anthesis

NFT= no frost tolerance

adapted from 'Managing Cover Crops Profitably', 'Northeast Cover Crop Handbook', 'Cover Crops for All Seasons'
For more details see also: Choosing the best cover crops for your organic no-till vegetable system, http://newfarm.rodaleinstitute.org/features/0104/no-till/chart.shtml

Depending on your cash crop, you can choose a winter or summer annual cover crop for organic no-till.

In northern regions, the cover crop needs to be cold tolerant to survive hard winters. Small grains (barley, oats, rye, and wheat) have good winter hardiness, grow rapidly, and seed is readily available. With their fast growth they are strong competitors against weeds, and some (such as rye) can be allelopathic, emitting chemicals that inhibit weed seed germination. Legumes, such as clovers, vetches, and peas, are less winter hardy than grasses, grow less rapidly, and are not as effective in preventing erosion or reducing leaching loss of left-over nitrogen. However, they add significant amounts of nitrogen to the soil (up to 200 lbs/acre) which is made available gradually to the following crop. The nitrogen availability pattern of these cover crops is more adapted to plant growth and needs than most mineral fertilizers.[24] To combine the advantages of both legumes and grasses, they can be planted in a mix. If the cover crop is terminated by rolling, however, the species in a mix will need to be flowering at the same time; otherwise the kill will not be successful.

Hairy vetch: Provides nitrogen and is very winter hardy

Crimson clover: Provides nitrogen and flowers early

Austrian winter peas: Provides nitrogen, less winter hardy than vetch

Winter rye: winter hardy, grows rapidly, has allelopathic properties

Choosing a winter annual has several advantages:

- The cover crop provides protection for the soil when it might otherwise be left bare
- The cover crop will flower and begin senescing in late spring, in time to plant warm season crops such as corn, soybeans, pumpkins, tomatoes or other vegetable transplants
- Summer annual weeds that germinate with the fall-planted cover crop won't survive the winter
- An established cover crop will inhibit weed germination in early spring

No-till corn into rolled vetch

No-till soybeans into rolled rye

No-till tomatoes

No-till pumpkins

No-till peanuts (photo credit: Mark Vickers, Georgia)

No-till eggplants (photo credit: Jeff Mitchell, UC Davis, California)

Sample rotations (adapted from 'Organic No-till Farming')

1. Grain/ forage rotation

This rotation is a 6-year rotation of corn, soybeans, oats and alfalfa. The alfalfa in year four, five and six provides a rest from the grain segment of the rotation, breaking pest and weed cycles and providing a significant nitrogen contribution. Since this is not a continuous no-till system, manure or compost can be incorporated in the fall before the cover crop is planted. In this example corn, soybeans and rye can all be planted without the use of primary tillage.

YEAR 1

Spring: Corn; hairy vetch (which was planted the previous fall (=Year 6) is rolled in early to mid June, and corn is planted into the rolled vetch which provides much of the nitrogen needed for the corn.

Fall: Rye - planted as soon as the corn has been harvested.

YEAR 2

Spring: Soybeans; rye is rolled in late May and soybeans are planted into the rolled rye.

Fall: Rye; this rye is strictly for winter cover if you plan to grow oats in Year 3. Alternatively, you can skip the oats, grow the rye to full maturity, and save your own seed.

YEAR 3

Spring: Oats; oats can be harvested for grain or cut for early forage. If harvested for grain, straw can be baled.

Fall: Winter wheat/alfalfa; winter wheat is planted in the fall, underseeded with alfalfa or alfalfa is frost seeded in late winter. (If there is no desire for a hay crop in the rotation, you can skip the alfalfa and proceed to Year 6 and plant hairy vetch in early fall following wheat harvest.)

YEAR 4

Summer: Winter wheat is harvested in July and the alfalfa continues to grow.

YEAR 5

Alfalfa: Alfalfa is harvested for hay (3-4 cuttings per year).

YEAR 6

Alfalfa/vetch; two to three cuttings are taken off the alfalfa during the summer. In the fall, the alfalfa is tilled under and vetch is planted as a winter cover crop for next year's corn and the rotation begins again.

2. Vegetable rotation

This rotation is an 8-year vegetable rotation based on an example in Eliot Coleman's book "The New Organic Grower". Depending on your latitude, additional crops may be squeezed in during the summer or fall. Again, this is not a continuous no-till system – tillage is performed in the fall to establish the winter cover crop, with manure or compost incorporated at that time. If desired, grains and legumes may be grown together for additional nitrogen with a carbon boost.

YEAR 1

Spring: Sweet corn; hairy vetch (which was planted the previous fall (=Year 8) is rolled in late spring and sweet corn is planted into the rolled vetch which provides much of the nitrogen needed for the corn.

Fall: Rye/vetch mix: vetch replaces some of the N lost with the sweet corn; rye provides adequate biomass for weed management.

YEAR 2

Spring: Potatoes - planted five inches deep into a raised bed. The rye/vetch cover crop is rolled two weeks later.

Fall: Rye - to be used as the cover crop for next year's summer squash.

YEAR 3

Spring: Summer squash - transplanted into rolled rye in early June.

Late summer: Buckwheat after summer squash, a quick smother crop of buckwheat is planted for additional weed suppression and phosphorus uptake.

YEAR 4

Spring: Radishes; an early planting of radishes is direct seeded into winterkilled buckwheat in April. The crop is mechanically cultivated. A mid-summer lettuce planting could follow, with supplemental nitrogen.

Fall: Rye - to be used as the cover crop for next year's beans.

YEAR 5

Spring: Snap beans; rye is rolled in early June, and beans are direct seeded into the rolled cover crop.

Fall: Vetch - to be used as cover crop for next year's tomatoes.

YEAR 6

Spring: Tomatoes; vetch is rolled in June, and tomatoes are transplanted into the rolled vetch.

Fall: Oats – to be used as cover crop for next year's peas.

YEAR 7

Spring: Peas - direct seeded into the winterkilled oat residue, mechanical cultivation is used.

Fall: Vetch - to be used as cover crop for next year's cabbage.

YEAR 8

Spring: Cabbage – vetch is rolled and cabbage is transplanted into the rolled vetch.

Equipment needed for no-till with cover crops

Roller - crimper

Rollers can vary in size and design and be modified to fit each specific operation. They can be purchased through I&J Manufacturing in Gap, Pennsylvania; free plans to build your own can also be downloaded from the Rodale Institute website. I&J rollers have standard widths of 8, 10½ and 15½ feet but they can be custom made narrower and wider (up to 40 feet wide).

I&J Roller Models

	Price	Weight
8' Model	$2,800	1,290 lb
10 1/2' Model	$3,200	1,680 lb
15 1/2' Model	$4,400	2,400 lb
30' Folding (3-point)	$18,300	
30' Folding (trailed)	$19,800	

Source: http://www.croproller.com/

10 ½ foot roller

Raised bed roller

The Rodale roller - crimper at a glance

HOW IT WORKS:
- Crushes the cover crop
- Crimps the stems of the cover crop every 7 inches

DESIGN FEATURES
- Front mounted on the tractor
- Ground driven
- Chevron pattern maximizes downward force while keeping the tractor on a straight course
- Drum can be filled with water to increase weight
- Easy to maintain (few bearings and areas where cover crops can become jammed)

SPECIFICATIONS
- Roller diameter: 16 inches
- 10 blades: 4 inches tall, spaced evenly around the roller
- Width: 8 feet (3 row), 10.5 feet (4 row), 15.5 feet (6 row); custom made rollers are available up to 40 feet wide
- Weight (10.5 ft roller): 1,680 lbs (empty), 2,400 lbs (filled with water)
- Hitch: made to fit category I or II 3-point hitch

Source: Organic No-Till Farming

3-point front hitch and hitch mounting frame

The roller can be pulled behind a tractor but the tractor tires may leave tire depressions in the cover crop, preventing the roller from making good contact with the cover crop and resulting in less than adequate kill. Mounting the roller on the front of the tractor will circumvent that problem and also free up the rear of the tractor for a planter or transplanter, allowing a one-pass operation of rolling the cover crop and planting the main crop. A special front 3-point hitch (plus a hitch mounting frame) is needed to mount the roller on the front of the tractor (available at Laforge Systems, Buckeye Tractor Company and Double R Manufacturing). Hitches can be installed on new tractors as well as tractors built since the 1960s and need to have a lift rating that allows you to raise the roller when it is full of water.

3-point front hitch

Front mounted roller (right) results in better cover crop kill than rear mounted roller (left)

No-till planter

To work through a rolled cover crop mat, standard no-till planters will probably need to be modified by:

- Adding weights to supply downward pressure and cut through the cover crop mat
- Using cast iron closing wheels (instead of the standard plastic and rubber wheels) to press through the mulch and close the seed slot
- Adding foam markers to help determine the location of the planter passes

In addition, coulters need to be well maintained to stay sharp and avoid hairpinning.

No-till transplanter

A regular transplanter may not be able to cut through the heavy mat of rolled cover crops. The sub-surface tiller-transplanter (SSTT) developed by Ron Morse of Virginia Tech is intended to transplant vegetable plugs into cover crop mats. The SSTT has an upright, high clearance design with a double disk opener plus a sub-surface tiller that prepares a narrow strip of soil up to 8 inches deep, which enables the double disk opener to open a furrow for the transplants.

No-till Monosem planter with modifications

Sub-surface tiller transplanter (photo credit: Mark Schonbeck, Virginia Association for Biological Farming)

Tractor

The tractor size will depend on the planter size. It must be able to pick the roller off the ground for turning.

High residue cultivator

A high residue cultivator can be a very useful tool if weeds start breaking through the rolled cover crop mat (a standard cultivator will most likely not be able to work with the large amount of residue left on the surface). Research trials at the Rodale Institute have been conducted with a cultivator manufactured by the Hiniker Company that has sharp coulter discs positioned between two depth control wheels, followed by large angled sweeps. The coulter disc cuts through the cover crop mat, creating a slit opening for the sweep to pass through. The sweep travels at a soil depth of a few inches, staying under the mulch mat without disturbing it too much and severing the weeds from their roots just below the soil surface. This cultivator works best when the soil is moist, the weeds are well established and large enough to be cut (but before seed setting) and the crop is still small enough for the equipment to easily pass through the field (about 5-6 weeks after planting).

High residue cultivator in no-till soybeans- the rye mat is sliced, but intact

Coulter disc and angled sweep

Equipment Budget Example

Roller-crimper	$3,200
Front End Hitch	$2,500
No-till Planter	$20,000
Planter Modifications	$460
Total cost:	**$30,600**

Based on: 10 ½ foot roller, 4 row-planter, planter modifications at $125/row
Source: Organic No-till Farming

Penn State researchers give these tips to farmers interested in trying organic no-till (Source: http://extension.psu.edu/susag/news/2011/Sept-2011/4-org-no-till)

1. **START SMALL.** Organic no-till is a significant change for many organic farmers and conventional no-tillers alike. Try it out on a small scale to minimize risk.
2. **CHOOSE WISELY.** Select cover crops that are moderately priced, easily established, highly productive, and easy to kill.
3. **PLAN AHEAD.** Due to the central role of cover crops in this system, planning must start far in advance of a given main-season crop.
4. **DON'T SKIMP.** Get cover crops in the ground on time and at recommended seeding rates. Successful weed suppression requires a dense mat of cover crop residues. If the cover crop looks less-than-ideal in spring, be ready with a plan B.
5. **STAY SHARP.** Keep equipment in good shape. To plant through thick residue, planting equipment must be maintained in top condition.
6. **BE CREATIVE.** Organic no-till will need to be adapted to each farm's climate, soils, equipment, and resources. But with the principles in hand, many solutions are possible.

The bottom line

The following tables compare production budgets for corn and soybeans in organic and conventional tilled and no-till systems but can be applied to other crops as well.

Main expenses for organic corn production are seeds, fuel and labor, whereas the biggest portion of the budget in the conventional systems is made up of fertilizers, herbicides and seeds. Compared to the tilled organic system, total expenses in the no-till organic system are more than 20% lower due to significantly lower labor, fuel and equipment costs. The no-till conventional system, on the other hand, has higher expenses than the tilled conventional system due to higher herbicide and seed costs and only a minor savings in fuel. Note that the conventional no-till system includes a hairy vetch cover crop before corn as part of best management practices. It is assumed that nitrogen fertilizer needs for corn can be reduced by approximately half because of residual nitrogen inputs from the vetch cover crop. Individual results may vary by location and year.

Production budgets for corn

	Organic Tilled	**Organic No-till**	**Conv Tilled**	**Conv No-till**
	vetch+corn	**vetch+corn**	**corn**	**vetch+corn**
Expenses				
fertilizer	0.00	0.00	118.04	90.44
herbicide	0.00	0.00	108.19	144.56
seed	139.40	139.40	88.15	148.35
custom haul	30.00	30.00	30.00	30.00
labor	39.35	18.61	15.78	16.14
fuel	47.60	23.96	23.76	20.67
repair & maintenance	17.56	10.35	8.42	8.97
interest on op. capital	6.35	4.54	11.50	13.50
fixed expenses	52.02	30.98	27.31	27.46
Total Expenses ($/acre)	**332**	**258**	**431**	**500**
Profit ($/acre)*				
@100 bu/a yield	**504**	**578**	**-16**	**-85**
@150 bu/a yield	**922**	**996**	**191**	**122**
@200 bu/a yield	**1,340**	**1,414**	**399**	**330**
Break-even price ($/bu)				
@100 bu/a yield	**3.32**	**2.58**	**4.31**	**5.00**
@150 bu/a yield	**2.22**	**1.72**	**2.87**	**3.33**
@200 bu/a yield	**1.66**	**1.29**	**2.16**	**2.50**

These production budgets were calculated using the free on-line Mississippi State Budget Generator (MSBG), developed by the Department of Agricultural Economics at Mississippi State University, (http://www.agecon.msstate.edu/what/farm/generator/). When available, input and price data were taken directly from data collected at the Rodale Institute (2008-2010), otherwise default values from the Budget Generator were used.
* The 3-year average price for organic corn was $8.36/bu, for conventional corn $4.15/bu.

Similar to corn production, the main expenses for organic soybean systems are seeds, fuel and labor, whereas seeds and herbicides comprise the biggest portion in the conventional system expenses. Lower labor, fuel and equipment costs reduce total expenses in the no-till organic system by 30% compared to the tilled organic system. As with corn, the no-till conventional soybean system has higher expenses than the tilled conventional system due to higher herbicide and seed costs and only minor savings in fuel and labor. Note again that the conventional no-till system includes a rye cover crop before soybeans as part of best management practices.

Production budgets for soybeans

	Organic Tilled	Organic No-till	Conv Tilled	Conv No-till
	rye+soybeans	**rye+soybeans**	**soybeans**	**rye+soybeans**
Expenses				
fertilizer	0.00	0.00	0.00	0.00
herbicide	0.00	0.00	16.32	35.79
seed	93.02	93.02	57.34	111.34
custom haul	8.00	8.00	8.00	8.00
labor	36.87	16.13	11.36	10.93
fuel	44.03	20.38	16.00	14.10
repair & maintenance	15.62	8.41	6.25	7.04
interest on op. capital	5.06	3.43	3.45	8.08
fixed expenses	46.70	25.66	20.10	21.20
Total Expenses ($/acre)	**249**	175	139	216
Profit ($/acre)*				
@30 bu/a yield	**314**	**388**	**168**	**90**
@40 bu/a yield	**502**	**576**	**270**	**193**
@50 bu/a yield	**689**	**763**	**373**	**295**
Break-even price ($/bu)				
@30 bu/a yield	**8.31**	**5.83**	**4.63**	**7.22**
@40 bu/a yield	**6.23**	**4.38**	**3.47**	**5.41**
@50 bu/a yield	**4.99**	**3.50**	**2.78**	**4.33**

These production budgets were calculated using the free on-line Mississippi State Budget Generator (MSBG), developed by the Department of Agricultural Economics at Mississippi State University, (http://www.agecon.msstate.edu/what/farm/generator/). When available, input and price data were taken directly from data collected at the Rodale Institute (2008-2010), otherwise default values from the Budget Generator were used.

* The 3-year average price for organic soybeans was $18.77/bu, for conventional soybeans $10.23/bu.

Energy comparisons

The following tables compare energy budgets for corn and soybeans in organic and conventional tilled and no-till systems. In this comparison the conventional no-till systems include a cover crop before the main crop. It is assumed that nitrogen fertilizer needs for corn can be reduced by approximately half because of residual nitrogen inputs from the vetch cover crop.

Corn production in a no-till organic system requires close to 30% fewer energy inputs than tilled organic corn production. The main energy savings result from reduced fuel and labor inputs due to a reduced number of field operations.

Energy differences are even bigger in a comparison with conventional corn production systems. Total energy requirements in the tilled and no-till conventional systems are more than 70% higher than their respective organic counterparts. More than half of the energy requirements in the conventional systems can be attributed to synthetic nitrogen fertilizer and herbicides.

Energy budgets for corn

	Organic Tilled	Organic No-till	Conv Tilled	Conv No-till
Energy inputs	**vetch+corn**	**vetch+corn**	**corn**	**vetch+corn**
Nitrogen fertilizer	0	0	9,875	4,942
Phosphorus fertilizer	0	0	391	391
Potassium fertilizer	102	102	118	118
Lime	203	203	243	243
Seed	2,559	2,559	1,182	2,468
Herbicide	0	0	1,055	1,509
Transportation of inputs	247	247	453	486
Equipment	639	615	619	509
Diesel fuel	5,359	3,046	2,725	2,201
Labor	1,041	511	712	563
Total energy (MJ/ha*yr)	**10,150**	**7,283**	**17,372**	**13,429**

This analysis was performed using the Farm Energy Analysis Tool (FEAT),[3] a simple database model used to analyze energy use of crops and cropping systems that are grown in temperate agroecosystems. The energy requirement associated with agricultural inputs are calculated based on their embedded energy required to produce that input.
Results presented here are based on actual input data collected from the Rodale Institute Farming Systems Trial, combined with the FEAT model which is based on a comprehensive literature review.

Total energy requirements in tilled and no-till organic soybean systems are very similar to the respective organic corn systems (both at about 10,000 and 7,000 MJ/ha/year respectively). The nearly 30% energy savings in the rolled cover crop no-till system are again due to fewer fuel and labor inputs.

Conventional soybean systems do not require nitrogen fertilizer inputs, therefore total energy requirements are significantly lower than for conventional corn. The no-till conventional soybean system is actually very similar to the no-till organic system. The only difference is that lower fuel energy requirements in the conventional no-till system are offset by the energy needed to produce the required herbicides.

Conventional soybeans in a tilled system without cover crops are the most energy efficient in this comparison: Although the tilled conventional beans required higher energy inputs for fuel and equipment than the no-till conventional soybeans, the tilled system's lower seed, herbicide and transportation inputs easily counterbalance those differences.

Energy budgets for soybeans

	Organic Tilled	Organic No-till	Conv Tilled	Conv No-till
Energy inputs	**rye+soybeans**	**rye+soybeans**	**soybeans**	**rye+soybeans**
Nitrogen fertilizer	0	0	0	0
Phosphorus fertilizer	0	0	0	0
Potassium fertilizer	102	102	118	118
Lime	203	203	243	243
Seed	3,441	3,441	1,532	3,287
Herbicide	0	0	408	893
Transportation of inputs	465	465	315	497
Equipment	639	615	586	461
Diesel fuel	5,047	2,733	2,110	1,593
Labor	701	188	200	196
Total energy (MJ/ha*yr)	**10,597**	**7,747**	**5,512**	**7,288**

This analysis was performed using the Farm Energy Analysis Tool (FEAT),[3] a simple database model used to analyze energy use of crops and cropping systems that are grown in temperate agroecosystems. The energy requirement associated with agricultural inputs are calculated based on their embedded energy required to produce that input.
Results presented here are based on actual input data collected from the Rodale Institute Farming Systems Trial, combined with the FEAT model which is based on a comprehensive literature review.

Resources

BOOKS, FACT SHEETS, ON-LINE INFORMATION

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http://extension.psu.edu/susag/news/2011/Sept-2011/4-org-no-till)

MSBG (Mississippi State Budget Generator), Department of Agricultural Economics at Mississippi State University. http://www.agecon.msstate.edu/what/farm/generator/

EQUIPMENT RESOURCES

Rodale Institute
611 Siegfriedale Road
Kutztown, PA 19530
Phone: 610-683-1400
Fax: 610-683-8548
www.rodaleinstitute.org/notill_plans

I&J Manufacturing
5302 Amish Road
Gap, PA 17527
Phone: 717-442-9451
Fax: 717-442-8305
www.croproller.com

Laforge Systems Inc.
4425-C Treat Blvd. - Suite 230
Concord, CA 94521
Phone 800-422-5636
Fax (925) 689-7198
lars@fronthitch.com
http://www.fronthitch.com/v3/pages/equipment.cfm

Buckeye Tractor Company
P.O. Box 97
11313 Slabtown Road
Columbus Grove, OH 45830
Phone 800-526-6791
Fax 419-659-2082
www.buctraco.com

Double R Manufacturing Ltd.
RR#2
Crapaud, PE C0A 1JO
Phone: 888-658-2088
Fax: 902-855-2030
http://doublermanufacturing.com/front-mount-3-point-hitch/

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Hiniker Company
58766 240th Street
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Phone 800-433-5620
http://www.hiniker.com

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SOIL HEALTH AND COVER CROP FACTS

Ten Ways Cover Crops *Enhance* Soil Health

Photo Credit: Rob Myers, North Central SARE

ABOUT SOIL HEALTH

Soil health is a hot topic these days, one that is justifiably receiving considerable attention from farmers and their farm advisors.

Whereas in the past, soil testing and evaluation focused more on chemical and physical measures, new research has shown that the biology of the soil is very important to its overall health and productivity.

An incredible diversity of bacteria, protozoa, arthropods, nematodes, fungi and earthworms create a hidden food web in the soil that affects how crops grow, how soil nutrients are cycled and whether rainfall is quickly absorbed into the soil and stays where crop roots can access that moisture.

The USDA Natural Resources Conservation Service (NRCS) has identified four basic principles or approaches for maintaining and improving soil health:

- **Keep the soil covered as much as possible**
- **Disturb the soil as little as possible**
- **Keep plants growing throughout the year to feed the soil**
- **Diversify crop rotations as much as possible, including cover crops**

Farmers can support these principles by using cover crops, which are conservation plantings of fast-growing annuals such as rye, clovers, vetches and radishes. Cover crops protect and improve the soil when a cash crop is not growing. In the case of summer commodity crops like corn and soybeans, cover crops can keep the soil covered in fall, winter and early spring. They make it easier to use no-till or other conservation tillage approaches that disturb the soil less, and they help with weed control. Plant diversity is helpful for soil organisms because it gives them a greater variety of food sources, and cover crops are an easy way to diversify a crop rotation that may otherwise see only one or two crops grown in a field. Adding cover crops to a rotation can greatly increase the portion of the year when living roots are present for soil organisms to feed on.

10 Key Impacts of Cover Crops on Soil Health

Besides contributing to the four basic goals or principles for soil health, there are a number of specific ways that cover crops lead to better soil health and potentially better farm profits.

1 Cover crops feed many types of soil organisms

Most fungi and bacteria that exist in the soil are actually beneficial to crops. Many of these soil fungi and bacteria feed on carbohydrates that plants exude (release) through their roots. In return, some fungi and bacteria will trade other nutrients, such as nitrogen or phosphorous, to the crop roots. While cover crops directly feed bacteria and fungi, many other soil organisms eat the fungi and bacteria, including earthworms and arthropods (insects and small crustaceans like the "roly poly"). Thus cover crops can help support the entire soil food web throughout the year.

2 Cover crops increase the number of earthworms

Earthworms are usually the most visible of the many organisms living in the soil. Cover crops typically lead to much greater earthworm numbers and even the types of earthworms. Some earthworms, like nightcrawlers, tunnel vertically, while other smaller earthworms, like redworms, tunnel more horizontally. Both create growth channels for crop roots and for rainfall and air to move into the soil.

3 Cover crops build soil carbon and soil organic matter

Like all plants, cover crops use sunlight and carbon dioxide to make carbon-based molecules. This process causes a buildup of carbon in the soil. Some of that carbon is rapidly cycled through the many organisms in the soil, but some eventually becomes humic substances that can gradually build soil organic matter. A higher level of soil organic matter improves both the availability of nutrients and soil moisture for crops.

4 Cover crops contribute to better management of soil nutrients

By building soil organic matter, cover crops can gradually impact the need for some types of fertilizer. Just as important to nutrient management is the way cover crops can scavenge or collect any nutrients left at the end of a growing season, such as nitrogen left in the field after corn is done growing. The cover crop will hold that nitrogen rather than letting it escape into tile lines leading to rivers and lakes or drain away into groundwater. Eventually that nitrogen will be released the next season to help the next year's cash crops.

5 Cover crops help keep the soil covered

When it rains on bare soil, the soil is much more likely to erode, form an impermeable crust and then overheat in summer when exposed to direct sun. Some bare soils can reach 140 degrees, hot enough to kill soil organisms and stress the crop from both heat and excessive soil moisture evaporation. The residue of a cover crop like cereal rye can protect the soil while cash crops are getting established and keep it from getting too hot.

6 Cover crops improve the biodiversity in farm fields

Generally, the more plant diversity in a field and the longer that living roots are growing, the more biodiversity there will be in soil organisms, leading to healthier soil. Growing mixes of cover crops or adding a few different cover crop species to an overall crop rotation—such as cereal rye before soybeans, and oats, radishes or crimson clover before corn—improves diversity. Many Corn Belt commodity farmers are adding a third cash crop to their rotation, usually a small grain such as wheat, and then using the earlier harvest of wheat to grow a more diverse mix of covers for several months. They sometimes graze those cover crop mixes for extra profit and because animal manure benefits soil biology.

7 Cover crops aerate the soil and help rain go into the soil

It's not just earthworms that open up soil channels for rain, but also the roots of the cover crops themselves. This is particularly the case where soil disturbance is minimal from tillage. The extra rain that gets into the soil instead of running off can make a big difference for crop yields, such as in mid-to-late summer in the Midwest, when the rain can come fast in thunderstorms and be followed by long dry spells. The extra aeration created by cover crop roots and earthworms also benefits crop roots and other soil organisms.

8 Cover crops reduce soil compaction and improve the structure and strength of the soil

The typical solution to compaction from heavy farm equipment has been more tillage, but that provides only the briefest of benefits while compounding the problem in the long term. Excess tillage destroys soil structure, while cover crops and the soil organisms they feed create the glue (glomalin) that binds soil particles together, leading to better soil aggregation and strong soil structure. Research has shown that cover crops (with an assist from earthworms) help loosen compacted soil even more effectively than subsoiling equipment, which takes a lot of diesel fuel. A field with cover crops and minimal tillage, or better yet no-till, will lead to much better soil structure without compaction issues.

9 Cover crops make it easier to integrate livestock with field crops

Beef cattle and other livestock are usually kept in pastures and out of crop fields, which has some conveniences but is not ideal for soil health. Think of buffalo herds foraging on prairies and you can see how natural systems evolved to have an integration of plants and grazing animals. The manure from livestock grazing on cover crops in a grain field can be beneficial for building organic matter and soil health. It is also a great way to get immediate profit from cover crops, as certain cover crop species can be very high-quality forage in late fall or early spring.

10 Cover crops greatly reduce soil erosion and loss

On many fields that have some slope to them, half the topsoil has already been lost from the days when they were first farmed. The future success of farming and our food supply depends on keeping the topsoil we still have, and cover crops are exceptional at helping stop erosion. Using no-till with cover crops can reduce erosion to a tiny fraction of what it would otherwise be in a conventional corn and soybean system. Even with some light tillage, a field with cover crops is still much better protected, especially with winter annual cover crops like cereal rye.

Summary

Methods of improving soil health come back to the core principles identified by NRCS, including a greater diversity of plants, keeping the soil covered, having living roots in the soil throughout the year and disturbing the soil less. As we learn more about soil biology, it's clear that even modest use of cover crops makes a big difference for soil health. Further information on cover crops, including publications and videos of farmers talking about cover crops and soil health, are available from SARE at www.sare.org/covercrops. More information and fact sheets on soil health are available from NRCS at www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health and from the Soil Health Institute at www.soilhealthinstitute.org.

SARE Sustainable Agriculture Research & Education

USDA United States Department of Agriculture National Institute of Food and Agriculture

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SOIL HEALTH INSTITUTE

The Soil Health Institute is a national non-profit organization working to safeguard and enhance the vitality and productivity of soil through scientific research and advancement.

December 2017

COVER CROP FACTS

Cover Crops at Work: Covering the Soil to Prevent Erosion

An overview of cover crop impacts on soil losses from agricultural production systems[1]

Photo Credit: Edwin Remsberg

ABOUT COVER CROPS

Cover crops are tools to keep the soil in place, bolster soil health, improve water quality and reduce pollution from agricultural activities.

- They include cereals, brassicas, legumes and other broadleaf species, and can be annual or perennial plants. Cover crops can be adapted to fit almost any production system.
- Popular cover crops include cereal rye, crimson clover and oilseed radish. Familiar small grain crops, like winter wheat and barley, can also be adapted for use as cover crops.

Learn more at www.sare.org/cover-crops

Cover Crops and Erosion

Cover crops can successfully decrease, or almost completely eliminate, soil loss from various production systems. They do this by:

- Providing coverage of the soil surface and protecting it from rain and wind
- Rooting into the soil profile and improving soil structure
- Encouraging water infiltration to the soil profile

Studies have shown decreases in soil loss from fields planted into different types of cover crops.

- Non-legume cover crops, including rye, ryegrass, triticale, barley, and wheat, reduced soil loss by 31% to 100% as compared to fields in which no cover crops were grown.
- Legume cover crops, including red clover, crimson clover, lentil and pea, reduced soil loss by 38% to 69% as compared to no cover crops.
- Mustard, a brassica, reduced soil loss by up to 82% as compared to no cover crop.
- On average, cover crops reduced sediment losses from erosion by 20.8 tons per acre on conventional-till fields, 6.5 tons per acre on reduced-till fields and 1.2 tons per acre on no-till fields.

Management Decisions Matter

- The best management practices for preventing soil loss are those that maximize ground coverage year-round, and these include no-till management in combination with cover crop growth.
- Conservation tillage practices were responsible for an 89% reduction in soil loss as compared to conventional tillage.

Cover Crops Can Steward Water Quality and Soil Health

- Erosion is a costly depletion of resources, a displacement of soil from where it is needed to where it becomes a pollutant in waterways. Displaced soil can carry nutrients, like nitrogen and phosphorus, which further pollute waterways.
- We can invest in reduced rates of soil loss from agricultural fields, whether in vineyard rows or corn fields, by planting cover crops, maintaining constant ground cover and utilizing no-till management.

[1] Unless otherwise cited, all data comes from a bibliography compiled by SARE and the University of Missouri.

SARE
Sustainable Agriculture Research & Education

This publication was developed by Sami Tellatin and Rob Myers of NCR-SARE and the University of Missouri under Cooperative Agreement No.83695601 awarded by the U.S. Environmental Protection Agency. EPA made comments and suggestions on the document intended to improve the scientific analysis and technical accuracy of the document. However, the views expressed in this document are those of the author. The EPA, the USDA and SARE do not endorse any products or commercial services mentioned in this publication. The SARE program is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2014-38640-22173.

July 2017

COVER CROP FACTS

Cover Crops at Work: Increasing Infiltration

An overview of cover crop impacts on water infiltration to the soil[1]


Photo Credit: Edwin Remsberg

ABOUT COVER CROPS

Cover crops are tools to keep the soil in place, bolster soil health, improve water quality and reduce pollution from agricultural activities.

- They include cereals, brassicas, legumes and other broadleaf species, and can be annual or perennial plants. Cover crops can be adapted to fit almost any production system.
- Popular cover crops include cereal rye, crimson clover and oilseed radish. Familiar small grain crops, like winter wheat and barley, can also be adapted for use as cover crops.

Learn more at www.sare.org/cover-crops

Cover Crops and Infiltration

Cover crops can successfully increase the infiltration of water into the soil layer. They do this by covering the ground with their biomass and by improving soil structure with their roots. Some specific mechanisms include:

- Preventing soil surface sealing (where the soil becomes impermeable after rainfall)
- Improving soil structure with increased soil aggregate stability, soil porosity and water storage capacity

Different types of cover crops may have different effects on infiltration because of their unique biomass growth and composition, and results vary based on how long the cover crop is grown.

- Non-legume cover crops, including bromegrass and rye, increased infiltration by 8% to 462%, based on a range of studies.
- Legume cover crops, including crimson clover, hairy vetch and strawberry clover, increased infiltration by 39% to 528%.
- Soil surface cover by residue alone increased infiltration by up to 180% in field trials.

Management Decisions Matter

Management that encourages continuous ground coverage by residues and cover crops will be best suited to positively impact the infiltration of water to the soil surface. Tillage practices are another important management decision for water infiltration.

- No-till management has been found to increase rainfall infiltration.
- One study reported that runoff from no-till fields was two to four times less than from conventional-till plots.

A Far-Reaching Solution

When water is able to enter the soil profile, rather than running off the soil surface, there is less risk of displacing soil particles through erosion. Increased infiltration also signals possible benefits to the water conditions within the soil profile. By keeping the soil in place and improving soil conditions, cover crops are mitigating pollution risk while also boosting the productive capacity of the soil.

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July 2017

Cover Crop Resource Series

COVER CROP FACTS

Cover Crops at Work: Increasing Soil Organic Matter

An overview of cover crop impacts on soil organic matter[1]

Photo Credit: Edwin Remsberg

ABOUT COVER CROPS

Cover crops are tools to keep the soil in place, bolster soil health, improve water quality and reduce pollution from agricultural activities.

- They include cereals, brassicas, legumes and other broadleaf species, and can be annual or perennial plants. Cover crops can be adapted to fit almost any production system.
- Popular cover crops include cereal rye, crimson clover and oilseed radish. Familiar small grain crops, like winter wheat and barley, can also be adapted for use as cover crops.

Learn more at www.sare.org/cover-crops

What is Soil Organic Matter?

- Soil organic matter is decomposed organic material (leaves, roots, microorganisms) that exists in the soil and acts as a reservoir of water and nutrients.
- Many analogies have been drawn likening organic matter in the soil to a sponge, a medium in which water and nutrients are stored.
- Soil organic matter is often a measure of a soil's fertility, and even a soil's resilience.

Cover Crops Increase Soil Organic Matter

- Cover crops are able to increase soil organic matter by protecting the soil surface from erosion, adding biomass to the soil (especially below the soil surface), and creating a habitat for microorganisms like fungi that contribute to the soil biology and provide more pathways for nutrient management in the soil ecosystem.
- Legume crops were found to increase levels of soil organic matter by 8% to 114%.
- Non-legume cover crops, including grasses and brassicas, were found to increase soil organic matter levels by 4% to 62%.

Soil Organic Matter is a Boon for Water Quality

- By providing these services, cover crops contribute to enhanced water quality because soil organic matter enhances soil processes and properties, including soil structure, and alleviates soil compaction.
- Additions of organic matter also increase water retention capacity, stabilize the soil during extreme weather events like drought or rainfall, and absorb and filter pollutants in runoff.
- Research into the composition of soil organic matter has shown that it's comprised of about 58% carbon.[2] Attempts have even been made to put a dollar value on soil carbon, asserting that restoring soil carbon levels could result in savings of about $25 billion per year.

In summary, cover crops are a good management strategy for increasing soil organic matter levels, a benefit that also has positive water quality, air quality and soil health implications. Cover crop management decisions are very important in maximizing their benefits, especially the decision to use no-till practices in conjunction with cover crops.

[1] Unless otherwise cited, all data comes from a bibliography compiled by SARE and the University of Missouri.
[2] Pribyl, D.W. 2010. A critical review of the conventional SOC to SOM conversion factor. *Geoderma*. 156(3-4):75:83.

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July 2017

Cover Crop Resource Series

COVER CROP FACTS

Cover Crops at Work: Keeping Nutrients Out of Waterways

An overview of cover crop impacts on nitrogen and phosphorus losses from agricultural systems[1]

Photo Credit: Edwin Remsberg

ABOUT COVER CROPS

Cover crops are tools to keep the soil in place, bolster soil health, improve water quality and reduce pollution from agricultural activities.

- They include cereals, brassicas, legumes and other broadleaf species, and can be annual or perennial plants. Cover crops can be adapted to fit almost any production system.
- Popular cover crops include cereal rye, crimson clover and oilseed radish. Familiar small grain crops, like winter wheat and barley, can also be adapted for use as cover crops.

Learn more at www.sare.org/cover-crops

Cover Crops Reduce Nitrogen Losses to the Environment

Nitrogen can be lost from agricultural fields in runoff water and groundwater. This displaced nitrogen may then travel into waterways and cause imbalances in the nutrient levels of these sensitive ecosystems. Farmers want nitrogen to remain on the land to fertilize their crops and support productive growing systems, and society as a whole doesn't want excess levels of nitrogen in the water.

- So how can cover crops help? They scavenge soil nitrogen and prevent it from being leached, and they can provide natural sources of nitrogen to cash crops and thus reduce the amount of fertilizer needed for production.
- Cover crops reduced the amount of nitrogen leaving a field by 1% to 89%, with a median value of 48% (across 10 studies and 16 observed reductions).

What About Phosphorous?

Compared to the impact of cover crops on erosion or losses of nitrogen, the impact of cover crops on phosphorus in the field is less studied and the research inconclusive.

- Phosphorus can be transported to waterways by above- or below-ground water flows.
- Some studies report finding no significant effect of cover crops on total phosphorus losses, sometimes because the cover crops may have reduced total phosphorus losses but increased soluble phosphorus losses (often in below-ground, leachate water).
- However, reductions have been observed, showing that cover crops reduced total phosphorus loads in water samples by 15% to 92%.
- The main mechanism by which cover crops may inhibit phosphorus losses is through preventing soil loss by covering the ground and rooting to secure the soil in place.

A Systems Approach to Enhanced Water Quality and Smart Nutrient Management

When faced with problems such as eutrophication and hypoxia in our waterways, we can turn to cover crops and other conservation practices as tools to mitigate this pollution.

- With cover crops, smart fertilizer- and manure-management decisions will also decrease nutrient-loss risks.
- Continuous ground cover paired with no-till management, will successfully prevent erosion and will therefore reduce above-ground nutrient losses to the environment.

SARE Sustainable Agriculture Research & Education

[1] Unless otherwise cited, all data comes from a bibliography compiled by SARE and the University of Missouri.

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July 2017

Cover Crop Resource Series

COVER CROP FACTS

Cover Crops Improve Soil Conditions and Prevent Pollution

An overview of cover crop impacts on erosion, infiltration, nutrient losses and soil organic matter on U.S. cropland[1]

Photo Credit: Edwin Remsberg

ABOUT COVER CROPS

Cover crops are tools to keep the soil in place, bolster soil health, improve water quality and reduce pollution from agricultural activities.

- They include cereals, brassicas, legumes and other broadleaf species, and can be annual or perennial plants. Cover crops can be adapted to fit almost any production system.
- Popular cover crops include cereal rye, crimson clover and oilseed radish. Familiar small grain crops, like winter wheat and barley, can also be adapted for use as cover crops.

In 2012, the USDA reported 10.3 million acres of U.S. cropland planted to cover crops.[2]

- Recent surveys by the SARE Program and the Conservation Technology Information Center (CTIC) suggest that cover crop acreage is increasing and illustrate that U.S. agricultural producers are intrigued by this conservation practice.
- With about 267 million acres of row crop agriculture in the U.S., the potential for cover crop adoption is quite higher than what has actually been achieved to date.[3]

Learn more at www.sare.org/cover-crops

Why Plant Cover Crops?

The scientific literature is ripe with data about the benefits of planting cover crops. Cover crops have been shown to decrease, or almost completely eliminate, erosion from agricultural fields, increase rainfall infiltration to the soil layer, keep nutrients like nitrogen and phosphorus in place and prevent the loss of these nutrients to vulnerable waterways, and increase soil organic matter (a measure of soil fertility).

Reductions in Soil Loss and Sediment Pollution of Waterways

- On average, cover crops reduced sediment losses from erosion by 20.8 tons per acre on conventional-till fields, 6.5 tons per acre on reduced-till fields and 1.2 tons per acre on no-till fields.
- Sediment is a costly pollutant in U.S. waterways, with estimated average sediment losses of 2.7 tons per acre per year across the U.S.[4]

Increases in Rainfall and Water Infiltration to the Soil

- Cover crops increased infiltration to the soil layer by more than six-fold in some systems.
- Improvements in rainfall infiltration to the soil surface signal two important benefits to cropping systems: decreased runoff and thus less erosion risk, and improved soil water and soil structural conditions that can benefit crop production.

Scavenging of Nitrogen and Prevention of Nutrient Losses to Waterways

Nitrogen can be lost from agricultural fields in runoff water and groundwater. This displaced nitrogen may then travel into waterways, and cause imbalances in the nutrient levels of these sensitive ecosystems.

- Cover crops have been shown to reduce these nitrogen losses by an average of 48% (concentration measurements, median of 10 studies), and as much as 89% in one study.
- Cover crops are able to successfully reduce nitrogen losses to waterways because they cover the ground and prevent runoff and erosion, and they scavenge soil nitrogen and keep it in place. Additionally, some cover crops can provide natural sources of nitrogen to other crops and thus can reduce the amount of fertilizer needed for production.
- Several sources also illustrated the ability of cover crops to reduce average total phosphorus loads to waterways by 15% to 92%, though more research on this is needed.

Photo Credit: Edwin Remsberg

Improved Soil Organic Matter Levels Signal Increased Soil Fertility and Soil Health

Soil organic matter is decomposed organic material (leaves, roots, microorganisms) that exists in the soil and acts as a reservoir of water and nutrients.

- Cover crops are able to increase soil organic matter by protecting the soil surface from erosion, adding biomass to the soil (especially below the soil surface), and creating a habitat for microorganisms like fungi that contribute to the soil biology and provide more pathways for nutrient management in the soil ecosystem.
- Legume cover crops were found to increase levels of soil organic matter by 8% to 114%.
- Non-legume cover crops, including grasses and brassicas, were found to increase soil organic matter levels by 4% to 62%.

Combining Management for Farm and Ecosystem Health

Cover crop management can be combined with no-till management and intentional manure management to create healthy conditions on the farm and in surrounding ecosystems.

- Like cover crop management, no-till management is also associated with reducing erosion and nutrient-loss risks in agricultural systems, especially when paired with cover crops and residue maintenance. One source showed that conservation tillage practices were responsible for an 89% reduction in soil loss as compared to conventional tillage.
- Manure application rates can be managed to mitigate losses of nitrogen and phosphorus to the soil, especially when cover crops are planted to offset any nutrient-loss risks posed by manure application.

A Proven Approach to Improving Our Ecosystems, Waterways and Soil Systems

The scientific consensus is in: cover crops reduce erosion, improve soil conditions and protect waterways from harmful nutrient loads. And, farmers and ranchers are curious about cover crops and are increasingly incorporating them into their systems. Though cover crop acreage has been rising each year, we still have enormous potential to increase the adoption of this beneficial practice and to improve our land and water quality for future generations.

[1] Unless otherwise cited, all data comes from a bibliography compiled by SARE and the University of Missouri.

[2] Myers, R. and C. Watts. 2015. Progress and perspectives with cover crops: interpreting three years of farmer surveys on cover crops. *Journal of Soil and Water Conservation*. 70(6):125A:129A.

[3] National Agricultural Statistics Service. 2016a. Acreage. www.usda.gov/nass/PUBS/TODAYRPT/acrg0616.pdf.

[4] Natural Resources Conservation Service. 2007 National Resources Inventory. National soil erosion results tables. www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=stelprdb1041678.

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July 2017

Reduced Tillage and Cover Cropping Systems for Organic Vegetable Production

Mark Schonbeck and Ron Morse

Virginia Association for Biological Farming Information Sheet

Number 9-07 4/01/07 http://www.vabf.org/pubs.php

Healthy living soils comprise the foundation for organic food and fiber production. Sustainable soil management integrates cover cropping, other organic and natural mineral inputs, and judicious tillage practices to obtain high crop yields (soil productivity), while building and maintaining high soil quality (long term production capacity). For more on biologically based soil building, see the VABF Information Sheet #2-06, *Caring for the Soil as a Living System.*

Cover crops play a key role in organic vegetable production because they protect and feed the soil, improve tilth, promote nutrient availability and balance, reduce weed pressure, and provide habitat for beneficial insects. Organic exudates from living cover crop roots sustain beneficial root-zone bacteria and fungi during off-seasons in annual vegetable rotations. For more on the benefits of cover crops see the VABF Information Sheet #1-06, *Cover Cropping: On-Farm, Solar Powered Soil Building.*

Tillage stimulates soil life, accelerating residue decomposition and release of soluble nitrogen (N) and other crop nutrients – and burning up organic matter in the process. Clean cultivation can facilitate crop establishment, but prolonged bare-soil periods increase the risk of erosion and crusting, depress soil biological activity and open niches for weed growth. Since 2003, the Virginia Association for Biological Farming has participated in a research effort coordinated by Professor Ron Morse and colleagues in the Horticulture Department at Virginia Tech to develop cover crop-based, reduced-tillage systems for organic vegetable production.

Contents:

The Organic Grower's Dilemma

Because organic production excludes the use of synthetic herbicides, organic vegetable growers rely on timely tillage and cultivation for weed control. Initial tillage to prepare the seedbed is normally followed by two or three additional cultivations to control weeds during crop establishment. Repeated tillage can damage soil structure, disrupt soil life, degrade organic matter, and increase the risk of soil erosion. Nothing is more devastating for the organic farmer than watching the farm's natural capital wash or blow away. Yet losing a crop to weeds because a timely cultivation has been missed, is little better.

Organic mulches, such as straw or spoiled hay, can reduce the need for cultivation, protect soil from erosion and crusting, and replenish organic matter. However, purchasing and spreading these materials may not be economically feasible in farm-scale production. Furthermore, mulch hay can carry weed seeds, and heavy annual applications may lead to soil nutrient imbalances.

Soil scientists in the USDA Natural Resources Conservation Service (NRCS) have developed a Soil Conditioning Index based on three key determinants of soil quality in agro-ecosystems: annual biomass input (cover crops and other residues), soil cover (vegetation or mulch) over the season, and tillage (the less, the better). This highlights the organic grower's dilemma: *how to manage weeds effectively without tilling the soil to death.* Researchers and growers are now seeking to address this challenge by:

- Maximizing the use of cover crops.
- Planting vegetables no-till into cover crop residues.
- Reducing frequency and intensity of tillage in general.

First Step: Maximize the Use of Cover Crops

The first step toward improving soil quality is to maximize cover crop biomass production within the existing crop rotation. Many vegetable growers plant winter cover crops such as cereal rye, hairy vetch and crimson clover in rotation with warm season vegetables like tomato, corn or squash. Not as many farmers grow cover crops at other times of the year, yet diversified crop rotations provide year-round opportunities to build soil health through cover cropping. Examples include:

•Oats, barley, field peas or vetch planted in early spring can add substantial organic matter ahead of July plantings of squash, cucumber or beans.

•Buckwheat can add organic matter and suppress weeds during short (30-45 day) time niches during the frost-free period.

•Millets, sorghum-sudangrass, cowpeas and soybeans can add tremendous biomass during a 60-day fallow between spring and fall vegetables.

•Non winter-hardy cover crops planted in July or early August and grown until they frost-kill can add biomass and protect the soil ahead of early spring vegetables.

The benefits of cover cropping can be maximized by using optimum planting dates, rates and methods, and by growing the cover crop to maturity (flowering but not setting mature seed). Guidelines for successful cover cropping, and information on a wide range of summer, cool-season and winter-hardy cover crops are given in the VABF information sheets #1-06, *Cover Cropping: On-farm Solar Powered Soil Building,* #3-06 *Cover Crops for All Seasons* and #4-06 *Using Manually-Operated Seeders for Precision Cover Crop Plantings on the Small Farm.*

Cover crops are most often incorporated into the soil as a green manure prior to planting the next vegetable crop. Mow heavy cover crops a few days before tilling. At the garden scale, scythe or weed-whack the cover crop and use clippings to mulch an adjacent bed or to make compost.

Tilling in cover crops (green manure) has some limitations. The freshly incorporated plant material makes the soil temporarily unfavorable to seed germination, so wait three to four weeks before planting. In a tight cropping schedule, this waiting period can delay vegetable planting beyond the optimum date, or necessitate earlier termination of the cover crop. Killing an annual cover crop three or four weeks early can cut biomass production by half.

Tilling in the cover crop accelerates soil organic matter decomposition and stimulates weed seed germination, thus compromising some of the benefits. Nevertheless, annual incorporation of high biomass cover crops can help build and maintain high soil biological activity.

Second Step: Plant Vegetables No-Till into Cover Crop Residues

In "organic no-till," an annual cover crop is grown to full bloom or early (not viable) seed formation, and killed mechanically by mowing, rolling, roll-crimping, or undercutting to form an *in situ* mulch, through which vegetables are planted without tillage. A good cover crop mulch can suppress weed growth until the vegetable crop has passed through its "critical weed-free period," usually the first five to seven weeks after planting for vigorous summer vegetables and transplanted brassicas. Tomato, pepper, brassica and pumpkin starts have been grown successfully in these systems, as have seed potatoes, garlic, onion sets and direct-sown peas, beans, corn and cucurbits. Small-seeded crops like lettuce, carrots and spinach may be stunted by allelopathy (production of natural substances that inhibit seedling growth) from the cover crop.

Over the past 20 years, farmers have had good results with no-till tomatoes and other summer vegetables in winter cover crop residues. Other cropping sequences that have given good results include early spring cover crops (oats, field peas) rolled/mowed in June-July for midsummer vegetables, and summer cover crops (millets, soybean, buckwheat) rolled/mowed in August for fall vegetables. Frost-killed residues of non-hardy cover crops for no-till garlic (planted in October) or spring vegetables (planted in March or early April) have given mixed results thus far.

No-till cover crop management maximizes cover crop biomass and soil cover, minimizes delays between the cover crop and the following vegetable, and helps control annual weeds. No-till reduces germination from the soil's weed seed bank, and the mulch itself retards weed growth through physical hindrance and allelopathic effects.

Generally, a grass + legume cover crop biculture is grown in order to realize both N fixation by the legume, and persistent, weed-suppressive mulch from the grass. In *zone planting*, the legume is planted in the location of future vegetable crop rows (e.g. the tops of raised beds) to provide N to the vegetable, and the grass is planted

Figure 1. The triticale cover crop (left) has accumulated about 2.3 tons/acre biomass and does not completely cover the ground. Spring weeds will likely grow through its residues before a no-till vegetable can get established. No ground is visible through the vigorous biculture of triticale + Austrian winter peas (right), which has reached 4.8 tons/acre, and will provide an effective, weed-suppressive mulch.

in the alleys and traffic lanes to maximize between-row weed suppression and moisture conservation.

Another variant of zone planting is a killed cover crop in the grow-zone, with alleys in a living mulch maintained by mowing. Examples include mow-killed soybean in the grow zone with alleys planted in browntop millet or sorghum-sudangrass (which regrow after mowing), or winterkilled legume or radish in the grow zone with rye in alleys. Although radish is not a legume, its succulent N-rich foliage decomposes rapidly after winterkill, yet suppresses winter weeds through an apparent allelopathic effect. Spring spinach and peas have thrived after radish in preliminary trials. Note that radish is *not* recommended in rotations with brassica vegetable crops due to the risk of clubroot and other diseases. In all these examples, the living mulch in alleys maintains weed suppression and can provide additional mulch material during vegetable production.

Four Keys to Success in Organic No-Till Planting:

•Establish high-biomass, solid-stand annual cover crops.

•Kill the cover crop, leaving a high residue, uniformly distributed mulch.

•Establish the vegetable crop with minimum disturbance of the killed mulch layer.

•Practice year-round weed management.

A good cover crop containing at least three tons (dry weight) aboveground biomass per acre is needed to obtain adequate weed suppression during the vegetable's minimum weed-free period. A *thick, solid vegetative growth* about three to four feet tall usually contains three tons per acre. The ground should not be visible when looking down on the cover crop from above.

Most annual cover crops can be killed at the late-bloom or early seed-development stages by mowing to a short stubble height. Exceptions include Japanese millet, browntop millet, sorghum-sudangrass hybrid, and possibly cowpea. A flail mower leaves the most uniform mulch, though the finely chopped residues break down fairly quickly, so that weed suppression may be shorter lived than with unchopped residues. Bush-hog rotary mowers tend to leave the mulch in windrows or random piles. If blades are kept sharp, the bush-hog can windrow residues uniformly enough for strip tillage (discussed later). At the garden scale, the cover crop is cut with a scythe or weed whacker, after which vegetables are planted manually.

Rye, barley, crimson clover, oats, buckwheat, pearl millet, foxtail millet and sunnhemp can usually be killed by *rolling*. Mulches of rolled cover crops persist longer and suppress weeds more effectively than flail-mowed residues. Rolling leaves cover crop stems oriented parallel to the direction of travel, which


Figure 2. The roller-crimper (left) has been developed specifically for no-till management of high biomass cover crops. The flail mower (right) is a versatile tool, in that it can be used to generate even, finely chopped mulch, or can be operated with the PTO off to function as a roller, as shown here.

is important for mechanical no-till planting. Vetches, peas and soybeans grown in biculture with these other cover crops will regrow somewhat after rolling. This regrowth can be managed by mowing a week or two later. Research teams in Virginia, Pennsylvania and Alabama have developed *roller-crimpers*, specifically designed for mechanically killing cover crops. The crimping action reduces regrowth. Rolling can also be accomplished with a cultipacker, or a flail mower with the PTO off. Even a tractor-mounted rototiller, again with the PTO off, can flatten and orient a stemmy cover crop, though two or three passes may be needed.

A third way to terminate cover crops without herbicides is frost-kill. July-planted sorghum-sudangrass, cowpea, pearl millet, soybean, and sunnhemp; and August-planted oats, radishes, and some varieties of field pea can produce substantial biomass before they winter-kill.

No-till vegetable planting can be the most challenging step, especially for small-scale farmers working with limited financial resources. Dr. Morse has developed the subsurface tiller-transplanter (SST-T), a


Figure 3. The No-Till Planting Aid (left) prepares a narrow slot in the soil for planting. This snap bean crop (right) was planted in August with a push seeder into furrows prepared with the planting aid. The cover crop residues helped the vegetable by conserving moisture during a hot, dry season.

tractor-drawn one- or two-row implement that parts the mulch, loosens a 2-inch wide by 6-8-inch deep slot in the soil, sets vegetable starts or seed potatoes, firms the soil around them, lays drip tape, and applies water or liquid (organic) fertilizer to the seedling, all in one pass. This is a major capital investment ($7-10,000 per row). For smaller farms, he has developed one- and two-row no-till planting aids (NTPA), which are much less expensive and can be drawn by a small (20-40 hp) tractor.

The NTPA, consisting of a heavy coulter and shank assembly, with an optional wavy coulter mounted behind the shank, slices the mulch and leaves a narrow (2-3 inch wide) swath of prepared soil. Vegetable starts or seeds are then planted manually or with conventional planting equipment.

Both the SST-T and the NTPA can function properly only when cover crop residues are oriented parallel to the direction of travel (by rolling) or chopped finely by flail mowing. Freeze-killed residues of stemmy, high-biomass cover crops should be rolled just prior to mechanical no-till planting.

Organic no-till vegetable planting should only be attempted in fields with good year-round weed management, few or no perennial weeds, and light to moderate seed banks of annual weeds. Keep the ground covered by vegetation and/or thick mulch as much as possible, and destroy weeds before they set seed. Problem weeds, such as nutsedge, Johnsongrass, docks, Bermudagrass and Canada thistle should be controlled before initiating no-till systems.

Organic No-Till Pitfalls

Because a cover crop mulch can delay soil warming and crop maturity, no-till planting is not recommended when earliness is an important objective, such as tomatoes for an early market. Cool wet soil conditions under the mulch can exacerbate problems with slugs, damping-off and some other fungal diseases. These problems occur most often in heavy soils, in cooler climates such as higher elevations in the Appalachian region, and in early spring vegetable plantings.

The organic grower will need to pay particular attention to crop N nutrition in no-till vegetable planting. Soil N will mineralize more slowly in the cooler, untilled soil under mulch. On biologically active soils, summer vegetables like tomato, corn and winter squash may obtain all the N they need from the soil's organic matter cycle regardless of tillage. However, fast-maturing spring vegetables like lettuce, spinach, broccoli and cauliflower require a *lot* of N from fairly *cool* soil in a *short* period of time. Organic no-till brassicas and greens will likely need side-dressing with fast-releasing organic N fertilizers to give satisfactory yields.

In very sandy soils and hot climates, tillage can cause N to mineralize *too* rapidly, so that the N is lost to leaching before crops can take it up. In these circumstances, no-till cover crop management and vegetable planting can enhance vegetable yields through better synchrony of N mineralization with crop N needs.

Perhaps the most common pitfall of organic no till is inadequate weed suppression by the cover crop residue. This can result from insufficient cover crop biomass (less than three tons per acre), large weed seed banks, or the presence of perennial weeds that are *not* effectively suppressed by mulch. Organic no-till should not be attempted during the first season after a field has been transitioned out of hay or pasture, because surviving fragments of tall fescue and other perennials can emerge readily through the cover crop mulch and compete severely with vegetable crops.

If a bad weed situation is detected *before* vegetable planting, it can be remedied by any of the reduced-till strategies discussed in the next section. If weed problems develop *after* vegetable planting, weeds can be pulled, mowed, removed with a high-residue cultivator, sprayed with an acetic acid herbicide allowed in organic production, or mulched over. Two or more of these measures may be needed.

Finally, *continuous* no-till is generally not feasible in organic annual crop production, because perennial weeds will eventually increase to a level at which tillage is required. Normally, some tillage is needed to plant the next cover crop after a no-till planted vegetable. Thus no-till organic vegetable planting should be viewed as one component of a *reduced tillage cropping system*. Depending on soil conditions and weed pressure, the field might require only light harrowing or shallow rototilling, or deeper tillage with a spading machine, chisel plow or rototiller. Deep inversion tillage with moldboard plow or heavy disk is usually not recommended as this can disrupt soil structure and soil life, and may create a hardpan.

Reduced Tillage Options for Managing Cover Crops

Some form of tillage is recommended when:

•The cover crop mulch is not thick enough to suppress

weeds for at least four weeks after vegetable planting,
•Weed pressure appears heavy, or
•No-till would delay soil warming or N mineralization sufficiently to hinder the vegetable crop.

Several reduced-till options for cover crop management include shallow tillage, zone tillage, strip tillage, and ridge tillage. Experiments have shown that shallow tillage (rototilled 2 inches deep) of winterkilled cover crops allowed early spring vegetables to yield at least as well as deeper (4-6 inches) tillage. A winterkilled cover crop followed by shallow tillage can give better weed control, less soil disruption and more organic matter input than a weedy winter fallow followed by deep tillage.

In zone tillage, the top of the raised bed (the vegetable grow zone) is tilled (shallow or deep as needed), while a killed or living mulch is left in the alleys and sides of the bed. Various strip tillage implements have been developed that clear and work up a narrow (8 to 12 inch) swath for vegetable planting, leaving much of the residue on the surface between tilled strips. Sometimes, a simple "sweep" or "duck foot" attachment can accomplish this, especially in a winterkilled cover crop. Though weeds will emerge within the tilled zone or strip and require hoeing or cultivation, these approaches can reduce soil disturbance and add organic matter, while providing rapid soil warming and N mineralization for the vegetable crop.

In ridge tillage, the field is shaped into ridges that correspond to the future cash crop rows, then planted in cover crop. Shortly before vegetable planting, the cover crop is mowed and the tops of the ridges are scraped off leaving a narrow, prepared seedbed, with plenty of surface residues left in the valleys between ridges.

At the garden scale, reduced till can be accomplished by cutting and clearing the cover crop (reserve clippings for mulch, or add to a compost pile), then shallow-tilling or strip-tilling. The roots and stubble are much easier to manage with garden tools than the entire cover crop biomass.

Perennial Sod Crops

Another way to reduce the intensity and frequency of tillage in a crop rotation is to alternate several years of annual crop production with several years in a perennial sod crop like hay or pasture. Three years in a diverse grass-legume sod can replenish soil and reduce annual weed pressure after a period of intensive vegetable production. This approach works best for diversified farms producing both vegetables and livestock, and for farms that have sufficient land area to keep 35-50% of working land in perennial sod at any one time.

Remember that the first year of transitioning out of any perennial sod is not the time to attempt no till vegetable planting. When hard-to-manage perennial weeds are present, plan on a two-year transition. Utilize grazing, tillage and smother cropping to: 1) eliminate existing vegetation, weed seeds and vegetative propagules (rhizomes, tubers, etc); 2) maintain soil health and organic matter level; and 3) produce a cash crop, if needed for farm income. *First*, deplete root reserves of the existing sod plants using repeated mowing and/or grazing for 6-8 weeks. Hogs can be especially helpful, as they root out and consume rhizomes of noxious perennials like Johnsongrass and Bermudagrass. *Second*, employ stale seedbed techniques for an additional 6-8 weeks, using non-inversion tillage implements (chisel plow, subsoiler, spader, power harrow) to uproot and desiccate perennial vegetation. *Third*, plant a diverse rotation of high-biomass cover crops and weed-competitive vegetables like sweet potato, winter squash, pumpkin, or crowder peas. Till after each crop

NOTE: while we normally do not recommend moldboard plowing, the moldboard plow may be the most practical means for some farmers to break sod. The plow should be set so that the furrow-slice is only partially inverted, so that air can reach the severed and decaying sod. Minimize erosion on moderate slopes, by plowing on the contour, or utilizing a contour strip-cropping system. Leave steeper slopes in sod if at all practical; otherwise plan on building terraces.

The Bottom Line

Plant cover crops wherever and whenever they fit into your crop rotation. Plant them well, and let them grow until they flower. Then manage them the best way you can, given available equipment, weed pressure, and vegetable crops to be grown. Till as little as practical, and as much as necessary to ensure adequate weed control, satisfactory vegetable yields and good cover crop stands. Even with some tillage, including one high-biomass (three to five tons per acre) cover crop per year can go far toward replenishing the soil's organic matter. Supplement with a little compost, aged manure and/or applied organic mulch, plus any amendments indicated by the soil test, and the soil food web will be well fed and will support good crops in the long run.

Resources – Equipment for Organic Minimum Till Systems

Dr. Ron Morse, Department of Horticulture, Virginia Tech, Blacksburg, VA 24061. Tel. 540-231-6724; e-mail morser@vt.edu, can provide up to date contact information for manufacturers of roller-crimpers, flail mowers, no-till vegetable planters and no-till planting aids.

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b

Iowa State University
Extension and Outreach

Cover Crops in Vegetable Production Systems


CEREAL RYE

SUSTAINABLE VEGETABLE PRODUCTION

www.extension.iastate.edu/vegetablelab

HORT 3026 June 2015

Current vegetable production systems require an intensive amount of work and inputs, and if not properly managed could have detrimental effects on soil and the environment. Practices such as intensive tillage, increased herbicide use, and reduced organic matter inputs add additional stress to the sustain ability of vegetable production systems. Growers need the tools and best practices to make production systems sustainable without compromising farm productivity and profitability. Cover crops serve as a valuable production tool in preserving environmental sustainability of vegetable cropping systems and render numerous benefits to soil, vegetable crops, and the grower.

What is a cover crop?

A cover crop is a crop that is not intended for harvest and is managed to maintain and improve soil fertility, water quality, and help manage weeds, pests, and diseases. Cover crops often are planted after harvesting a vegetable crop and then terminated before the planting of the next vegetable crop. There also are production systems where cover crops are used as living mulch, growing at the same time as the vegetable crop.

Benefits of cover crops

Cover crops provide a wide range of ecological and environmental benefits. Depending on cover crop type and grower needs, each cover crop can be utilized to provide a specific ecological benefit. Table 1 provides a list of cover crops used in vegetable cropping systems. Some of the primary benefits which cover crop provide include:

Soil and water conservation

With the use of intensive tillage in vegetable production systems, there is a constant threat of soil erosion due to rain and wind. Cover crops prevent soil erosion by providing ground cover and plant roots to hold the soil.

Both the living foliage and the residue from dead cover crop plants protect the soil from rain drop impact and slow water and air flow across the soil surface, which reduces dislodging and movement of soil particles. The cover crop root system helps to hold soil in place by enmeshing and anchoring soil aggregates. Successive years of cover crop plantings can indirectly contribute to water conservation by

TABLE 1. Cover crop characteristics for vegetable cropping systems

Cover crop	Seeding rate* (lb/A)	Planting times	Expected biomass (lb/A)
Brassicas			
Oilseed radish	10-12	Spring, late summer, early fall	4,000-6,000
Rapeseed	10-15	Fall, spring	2,000-4,000
Yellow mustard	10-12	Spring, late summer	4,000-8,000
Legumes			
Cowpeas	75-100	Early summer	2,500-5,000
Crimson clover	25-30	Early/late summer	3,500-5,000
Field peas	90-100	Fall, early spring	4,000-5,000
Hairy vetch	25-40	Early fall	2,500-5,000
Red clover	10-12	Early spring, late summer	2,000-5,000
Sweet clover	10-20	Spring	3,000-5,000
White clover	10-12	Spring, early fall	2,000-5,000
Non-legumes			
Annual ryegrass	20-30	Late summer, fall	3,000-5,000
Barley	75-125	Fall, spring	4,000-6,000
Buckwheat	50-80	Spring, late summer	2,000-5,000
Cereal rye	100-120	Late summer, fall	4,000-8,000
Oats	100-120	Early spring, late summer	4,000-8,000
Sorghum sudangrass	40-50	Late spring, early summer	8,000-12,000

* Seeds broadcasted

increasing soil organic matter, which improves soil water holding capacity and infiltration. Successive years of cover crop plantings can indirectly contribute to water conservation by increasing soil organic matter, which improves soil water holding capacity and infiltration.

Organic matter input

A primary advantage of growing cover crops is the addition of organic matter to the soil. Organic matter improves the physical condition of the soil by improving the structure, aggregate stability, water holding capacity, and porosity of the soil. Also, organic matter from cover crops improves nutrient cycling by increasing soil microbial population and activity. Examples of cover crops that can add substantial organic matter to soil include cereal rye, oats, sorghum-sudangrass, and triticale.

Nitrogen fixation

Leguminous cover crops such as clovers and vetches, have the added advantage of fixing atmospheric nitrogen for their growth and the following crops. This nitrogen fixation occurs through a symbiotic

relationship between the leguminous plant and nitrogen-fixing bacteria that live in nodules (knobs) on the plant's roots. While the bacteria fix nitrogen for plant growth, the plant provides food and shelter to the bacteria. Upon death of the legume the nitrogen is released and around 40%–60% of the nitrogen in the legume cover crop is available to the next crop. The amount of nitrogen contributed by legumes varies by species (see Table 2). There are specific species of bacterium that form symbiotic relationship with individual legume cover crop species. It is advisable to inoculate legume seeds with the proper nitrogen-fixing bacterium strain for efficient nitrogen fixation. The cost for the inoculum packet is \$5–\$10 and can usually treat 50 pounds of seeds. Research has shown significant increase in cover crop biomass and nitrogen-fixing potential in inoculated legume cover crop systems.

TABLE 2. Nitrogen fixation estimates by leguminous cover crops

Cover crop	Nitrogen contributed (lb/A)
Crimson clover	50-125
Hairy vetch	100-120
Red clover	75-130
Sweet clover	50-125
White clover	80-130

Nutrient scavenging
Cover crops planted in the fall can scavenge and use unused soil nitrogen left at the end of the growing season, which may have otherwise leached during the fall or the spring. Certain cover crops tend to be very efficient at recycling or scavenging excess nutrients such as oilseed radish, cereal rye, yellow mustard, etc. These species are well adapted to cool, fall and spring conditions, and continue growing after nutrient absorption by the crop has slowed or stopped. When the cover crop dies, most of the nitrogen used by the plant during growth will be released and reused by future crops.

Break soil compaction
Cover crop roots can help alleviate the effects of soil compaction by penetrating a compacted layer and creating macropores or root channels that allow air, water and crop roots to penetrate deeper in the soil profile. Although all cover crop species contribute to loosening of soil, cover species differ in their capacity to penetrate compacted soils. In general, cover crops, such as oilseed radish, have large diameter taproots and are more effective at penetrating compacted soil layers than species that have small diameter roots. Once these taproots penetrate the restricting soil layer they are able to bring up nutrients from deep soil layers to upper layers of the soil.

Enhance soil biology
Soil is a living entity and is home to hundreds of thousands of different worms, insects, nematodes, and microorganisms. To keep soils healthy and improve soil quality, the value of cover crop root and shoot residues that help feed the soil throughout the entire year should be recognized.

The top 6 inches of soil can contain over 2,500 to 5,000 lbs./acre of living organisms. Cover crops improve the soil environment for both macro- and microorganisms, of which the majority are beneficial or not a problem for a vegetable crop. Cover crop residues increase soil organic matter, improve water holding capacity, provide a food source, and moderate soil temperature, all of which benefit soil macro- and microorganism communities. Several studies have shown higher soil microbial biomass and diverse soil microbial populations under cover-cropped systems. Cover crops also promote populations of soil macrofauna such as earthworms, millipedes, beetles, and spiders, which help create air pore spaces in the soil.

Bio-fumigation

Cover crops can be used to suppress problematic plant pathogenic nematodes, bacteria, and fungi in the soil. Certain cover crops in the Brassicaceae family (plants with cross-shaped petals) produce biologically active compounds, called glucosinolates, that have shown activity on soil-borne pests. Glucosinolates are present in plant roots, shoots, stems, and leaves and when incorporated into the soil they break down into compounds called isothiocyanates (ITCs) and other chemicals. The ITCs are known to suppress soil-borne diseases, nematodes, and weed seeds. Some cover crops that belong to the Brassicaceae family include oilseed radish, canola, Indian mustard, brown mustard, and yellow mustard. It is important to note that these cover crops cannot be used as a sole control measure to mitigate soil pest problems; rather they should be used to enhance management strategies. Additionally, there is variability in the biofumigation capabilities, a technique of incorporating a plant's biomass into the soil, which will release toxic volatiles that suppress pests, among varieties of cover crops. For example, oilseed radish cultivars such as Adagio and Ultimo which have European origin, are reported to give better nematode suppression (especially cyst nematodes) than other cultivars. Oilseed radish cultivars commercially available and commonly grown in United States include Defender and Daikon.

Weed suppression

Cover crops can be used to manage weeds in vegetable production systems. Cover crops can reduce weed germination and establishment by competing and/or producing allelochemicals, which suppress weed seed germination. Cover crops such as cereal grains and grasses establish quickly in the fall, cover the soil, and grow throughout the winter, thereby suppressing fall and winter weeds. Small-seeded legumes that are seeded in the fall are sometimes not a good choice for weed suppression as they grow slowly during cold weather and can be outcompeted by weeds. Cover crops can influence weeds either in the form of living plants or as plant residue remaining after the cover crop is killed.

Crop rotation

Crop rotation is a planned system of growing different crops in succession on the same land. Benefits of crop rotation in terms of weed, pest, and disease management are well documented. Cover crops can be used in crop rotation plans to break pest cycles, add organic matter, and improve soil quality and health. Vegetables have many potential seasons of production, and given the choices available with long- and short-term cover crop life cycles, cover crops can easily fit into any crop rotation plan. Periods of 1–2 months between harvest of early planted spring crops and planting of fall crops can be filled using fast-growing, warm-season cover crops, such as buckwheat, cowpea, oats, and sorghum-sudangrass. Table 3 (page 6) provides a few examples and scenarios of how cover crops could be integrated with vegetable cropping systems.

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TABLE 3. Examples of integrating cover crops in vegetable cropping systems

Year	Month*	Season	Example 1	Example 2	Example 3	Example 4	Example 5	Season	Month*	Year
		Fall (previous year)	Oats + peas	Cereal rye + hairy vetch	Oilseed radish	Cowpea	Yellow mustard	Fall (previous year)		
YEAR 1	March	Spring	Winter-killed field peas		Winter-killed oilseed radish	Winter-killed cowpea	Winter-killed yellow mustard	Spring	March	YEAR 1
	April		Onion						April	
	May				Lettuce	Sweet corn	Muskmelon		May	
	June	Summer		Pumpkin				Summer	June	
	July								July	
	August		Crimson clover		Buckwheat	Buckwheat			August	
	Sep	Fall			Cauliflower		Cereal rye + hairy vetch	Fall	Sep	
	Oct					Garlic			Oct	
	Nov			Cereal rye	Cereal rye				Nov	
YEAR 2	March	Spring	Winter-killed crimson clover					Spring	March	YEAR 2
	April		Potato						April	
	May			Broccoli					May	
	June	Summer			Eggplant or pepper		Sweet potato	Summer	June	
	July								July	
	August		Sorghum sudangrass			Sorghum sudangrass			August	
	Sep	Fall		Buckwheat				Fall	Sep	
	Oct				Triticale		Triticale		Oct	
	Nov								Nov	
YEAR 3	March	Spring	Winter-killed sorghum sudangrass	Winter-killed buckwheat		Winter-killed sorghum sudangrass		Spring	March	YEAR 3
	April			Carrot			Cauliflower		April	
	May		Sweet potato		Onion				May	
	June	Summer				Pumpkin or winter squash		Summer	June	
	July						Buckwheat		July	
	August			Crimson clover			Lettuce or spinach		August	
	Sep	Fall			Oats + field peas			Fall	Sep	
	Oct		Cereal rye				Cereal rye		Oct	
	Nov					Cereal rye			Nov	
YEAR 4	March	Spring		Winter-killed crimson clover	Winter-killed oats + field peas			Spring	March	YEAR 4
	April					Potato			April	
	May			Sweet corn	Cucumber		Pepper		May	
	June	Summer	Cucumber					Summer	June	
	July								July	
	August					Cowpea			August	
	Sep	Fall	Oats + field peas	Cereal rye + hairy vetch	Oilseed radish		Yellow mustard	Fall	Sep	
	Oct								Oct	
	Nov								Nov	
YEAR 5			Return to Year 1	Return to Year 1	Return to Year 1	Return to Year 1	Return to Year 1			YEAR 5

* Months indicate planting time for crops. Planting time within a month may vary based on weather conditions.

Conclusion

Cover crops are gaining importance and are becoming an integral part of vegetable cropping systems. They improve the sustainability of vegetable production systems by reducing soil erosion, compaction and synthetic nitrogen inputs, suppressing weeds, increasing soil organic matter and water infiltration, enhancing soil biology, and providing habitat for beneficial insects and natural enemies of pests.

Resources

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Page 3, crimson clover illustration (Source: Britton, N.L., and A. Brown. 1913. An illustrated flora of the northern United States, Canada and the British Possessions. 3 vols. Charles Scribner's Sons, New York. Vol. 2: 355.

Page 5, buckwheat illustration by Spline_x (iStock.com)

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