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 [illegible]*

Handbook

Tuesday [illegible]
([illegible] 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, chs82@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

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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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

NEW YORK SOIL HEALTH

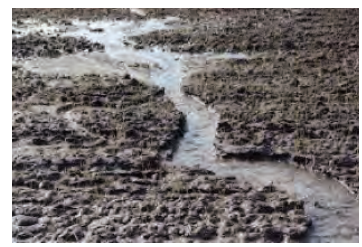
Current Priorities and Plans for 2018-2019

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

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.

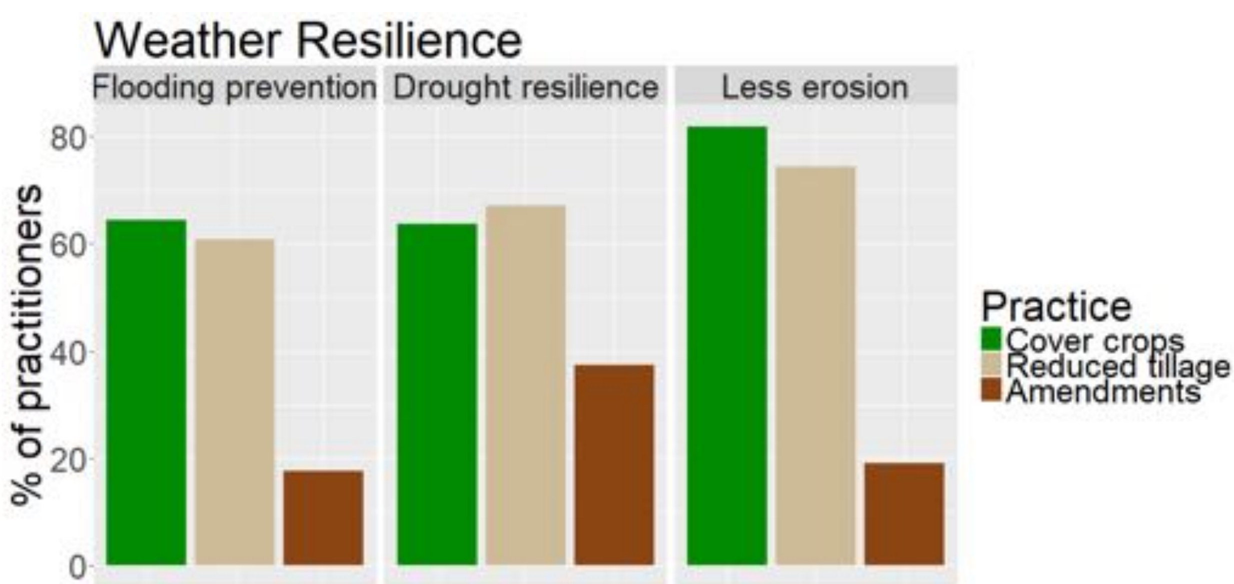


Figure 1: Soil health practices and their impact on resilience to extreme weather events.

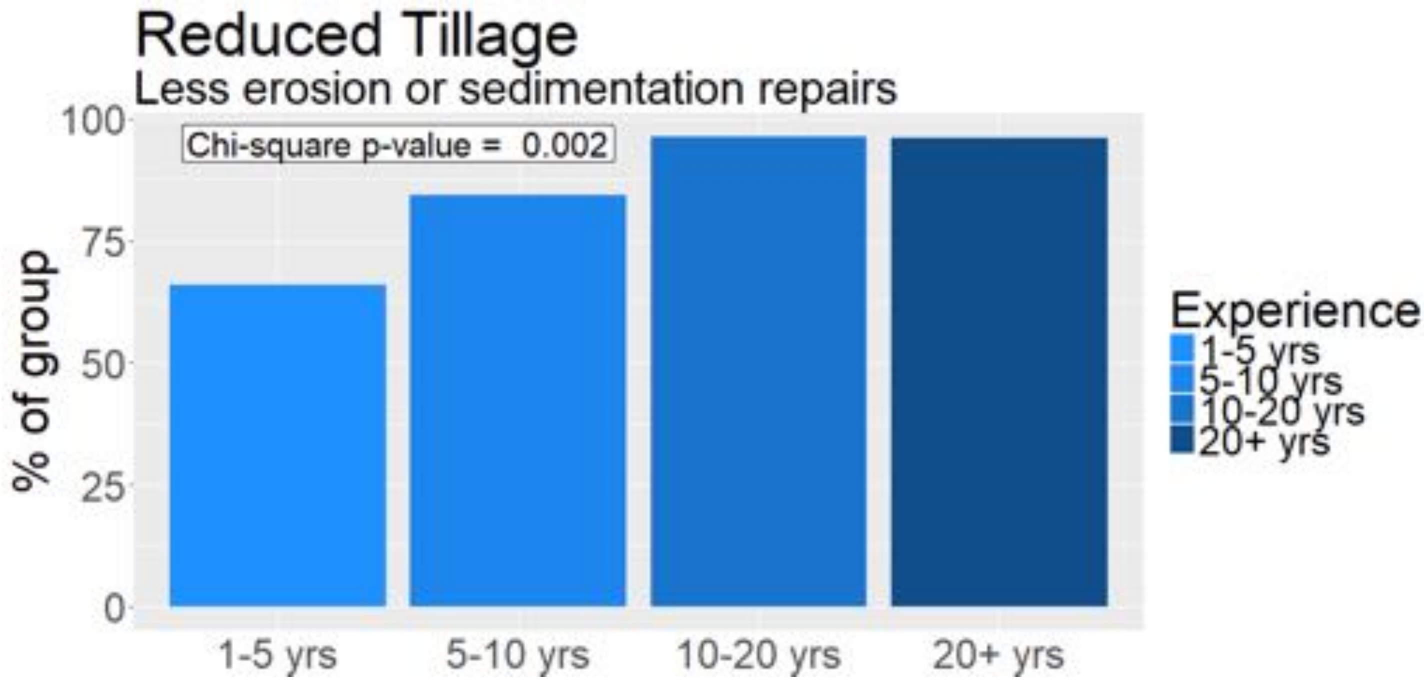


Figure 2: Prevalence of decreased erosion among reduced tillage practitioners at various levels of experience.

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.

Lake Champlain Basin Program

NEIWPCC
New England Interstate Water Pollution Control Commission

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

Cornell University

MICHIGAN STATE UNIVERSITY

1865 THE UNIVERSITY OF MAINE Cooperative Extension

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.

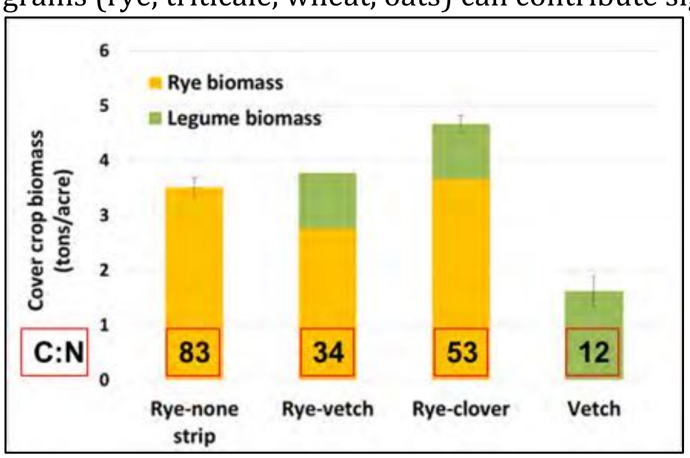
Question - How do we maximize cover crop benefits for zone-till and balance weed, nitrogen, and residue management challenges to be successful?

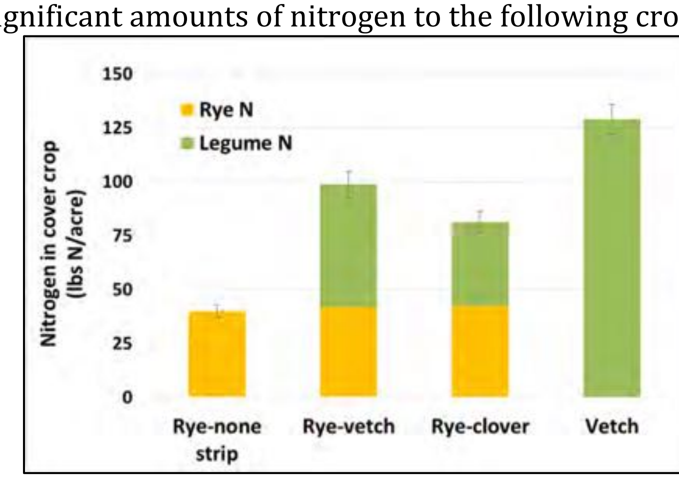
Zone tillage is a system that goes beyond the tillage tool.

Key decision points

- **<u>Late Aug to mid-Sept</u> -> 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
- **<u>Late May to mid-June</u> -> 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
- **<u>Mid-June to early July</u> –> Tillage and cash crop planting –** e.g. intensity of tillage, row cleaners, planter
- **<u>July to Aug</u> -> 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.



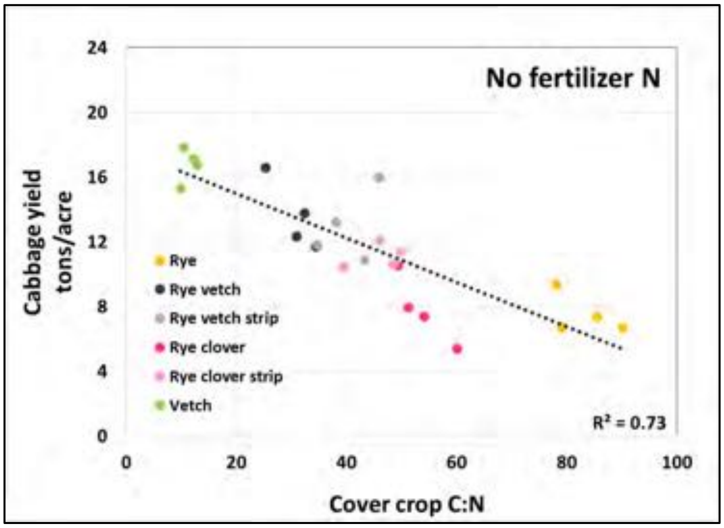


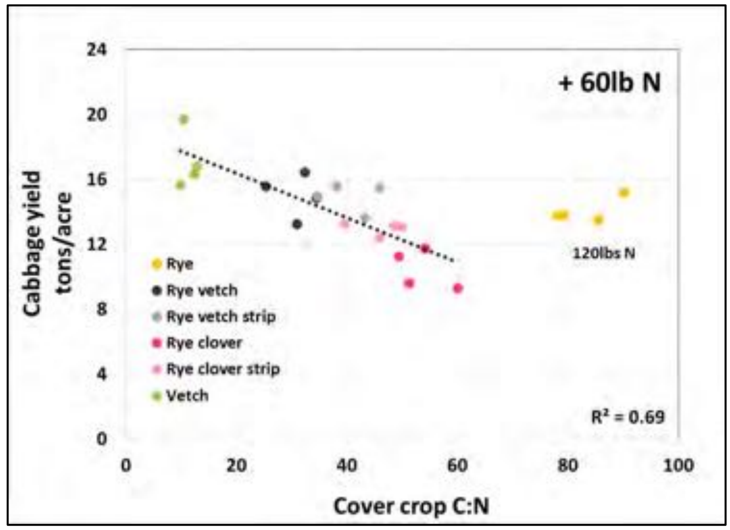
Cover crops and mowing equipment effect residue interference for planting. Row cleaners are very important for building clean planting zones in high residue and work best after flail mowing. Flail mowers finely chop and lay biomass evenly compared to a rotary mower and front or side-mounted units avoid 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.

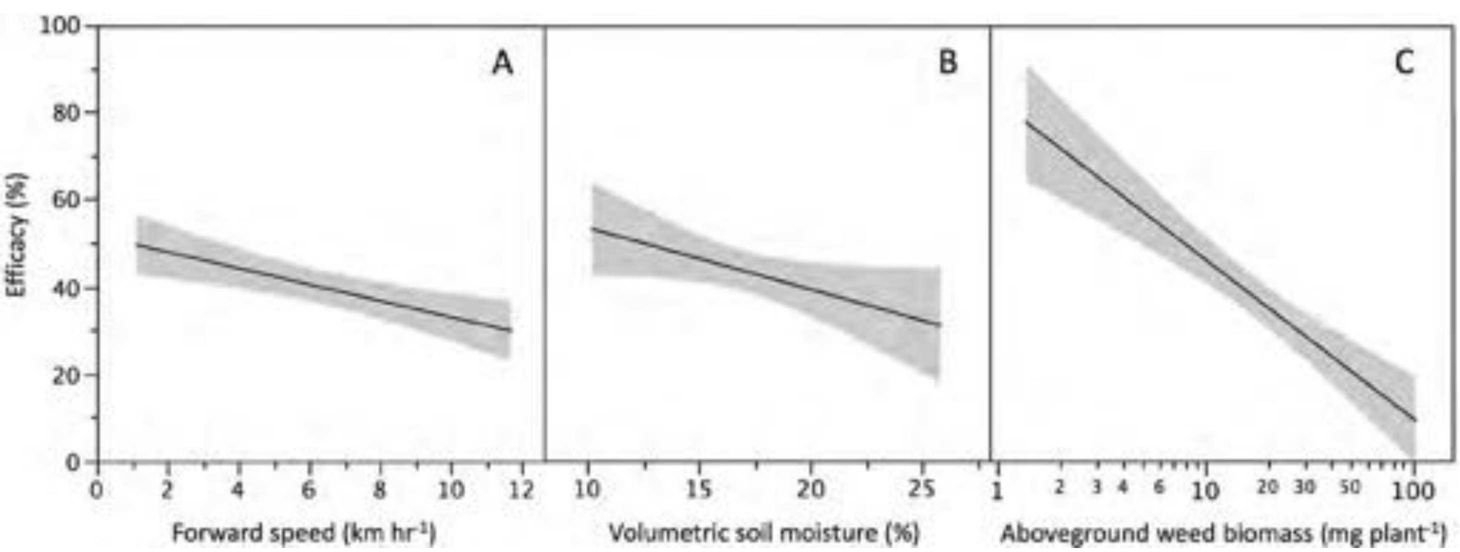


Figure 1. Averaged efficacy (weed control) of torsion, finger, and harrow weeders as tractor forward speed (A), soil moisture (B), and weed size (C) varied. Effectiveness was most strongly affected by weed size. The effect of speed was counter-intuitive and demonstrated that in-row tools need to be set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

John Wallace
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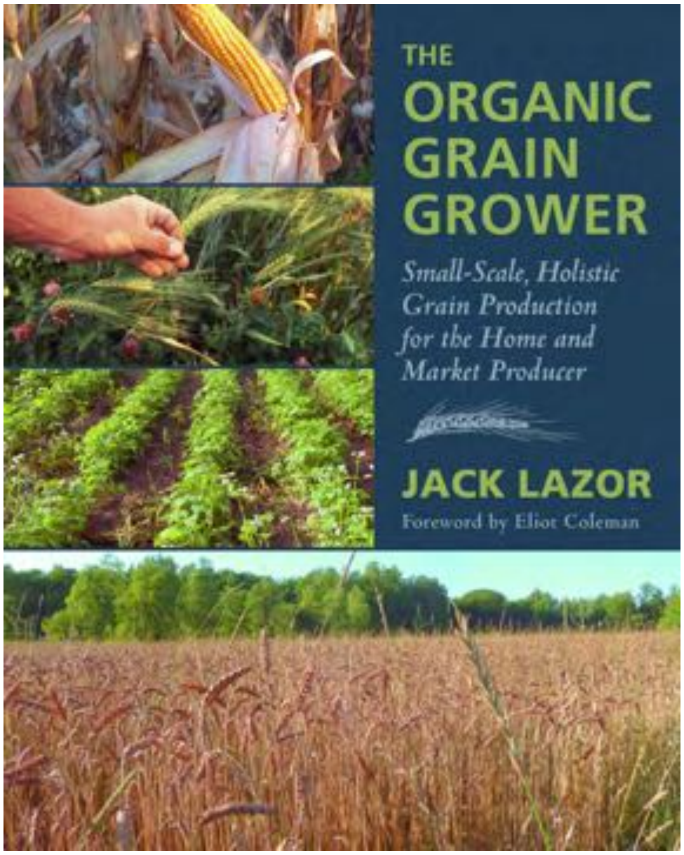
CornellCALS
College of Agriculture and Life Sciences



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.

RUTGERS
New Jersey Agricultural
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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

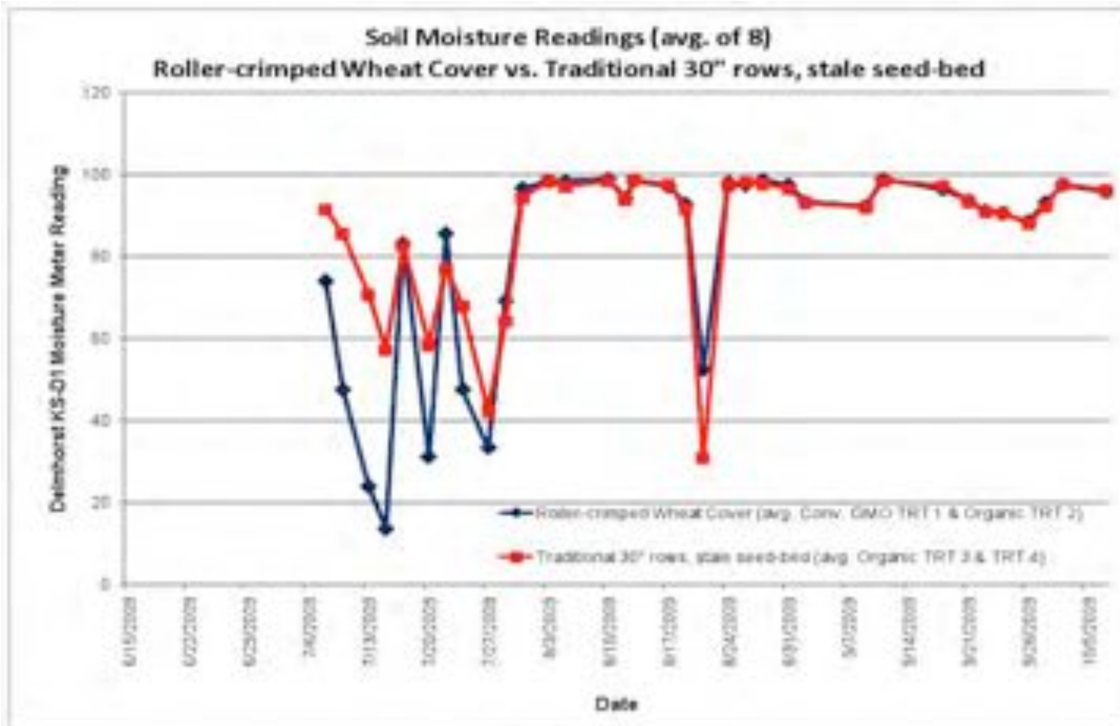
- Roll cover crop in parallel swaths before lodging to minimize binding at planting.
- Delay planting 1-2 weeks or use burndown herbicide at termination to desiccate cover crops.
- Hand transplant or seed smaller fields.
- Plug planters can be adapted to direct seeding pumpkin or squash by dropping seeds 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).

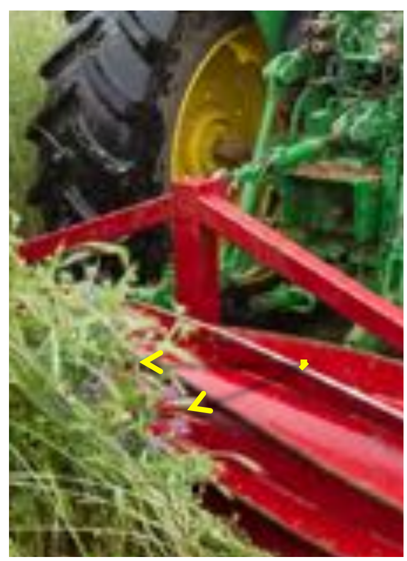
Solutions: Delay planting, drip irrigate transplants, apply burndown herbicide

- 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

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

STATEWIDE: **Chris Lawrence, USDA-NRCS**, (804) 287-1680 or *chris.lawrence@va.usda.gov*

SHENADOAH VALLEY:

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NORTHERN COASTAL PLAIN:

Craig Brann, Northern Neck SWCD
(804) 333-3525 x3 or *craig.brann@va.nacdnet.net*

Jonathan Chilton, Three Rivers SWCD
(804) 443-3571 x3 or *robert.chilton@va.nacdnet.net*

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.

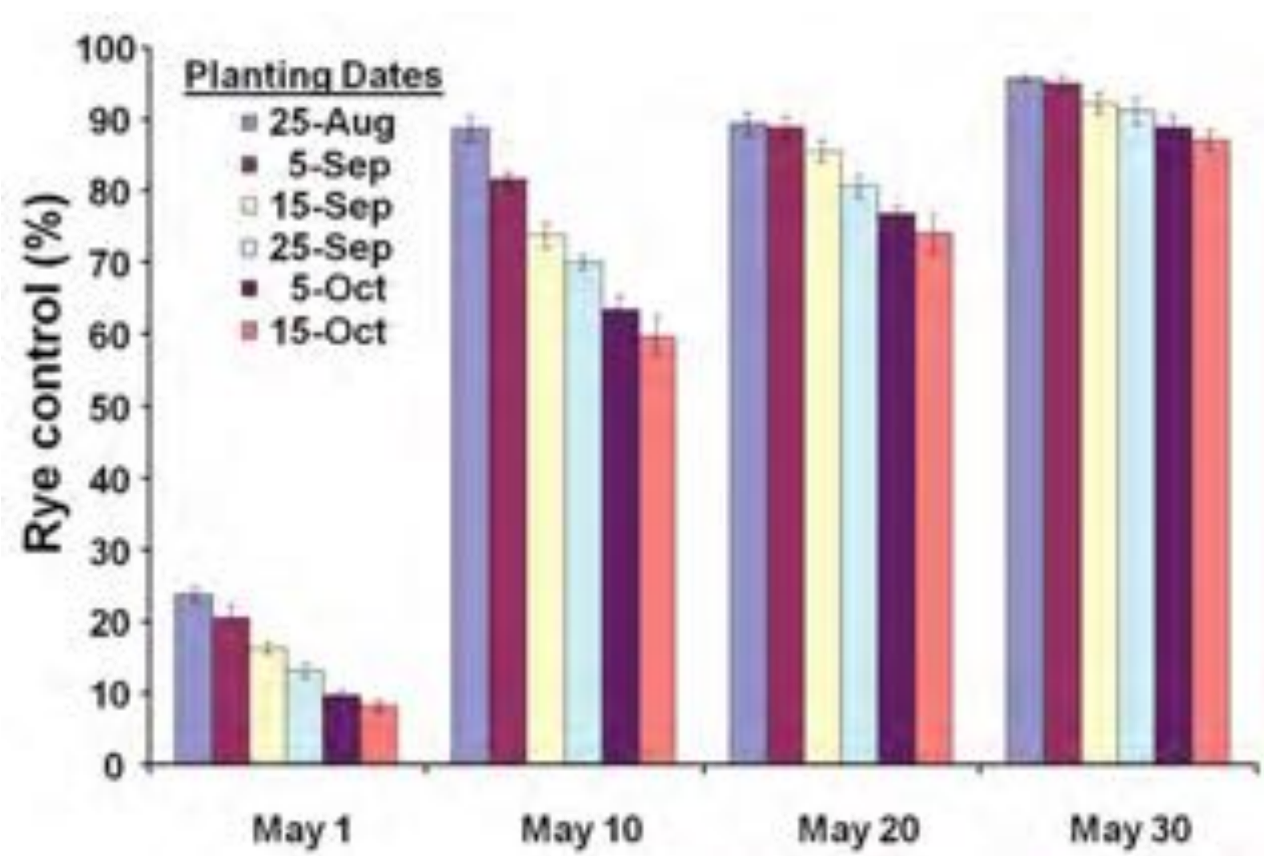

Figure 1. Percent control of cereal rye 6 weeks after rolling as influenced by planting date (Aug. 25-Oct. 15) and termination date (May 1-May 30). Bars represent standard error of the means. By the May 30 termination, fall planting date was not important--all dates were effectively controlled. Experiment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

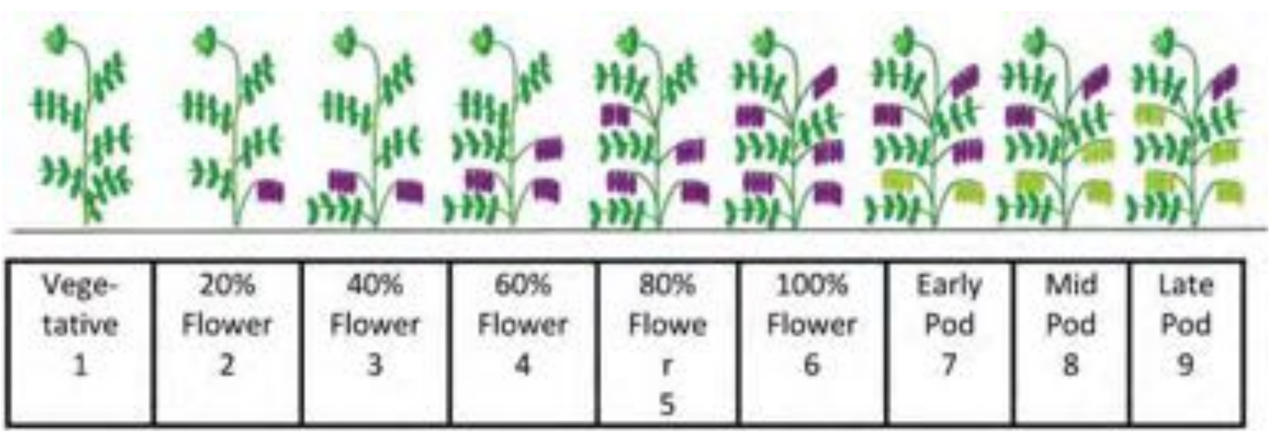

Figure 2. Hairy vetch growth stages based on the upper five nodes of the vine. Growth stage depends on the number of buds that have begun to bloom or produce pods. Vegetative (1), no flower buds are visible; early pod set (7), when 1-2 pods are visible; and late pod set (9) when 4+ pods are visible. 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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THE OHIO STATE UNIVERSITY EXTENSION

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

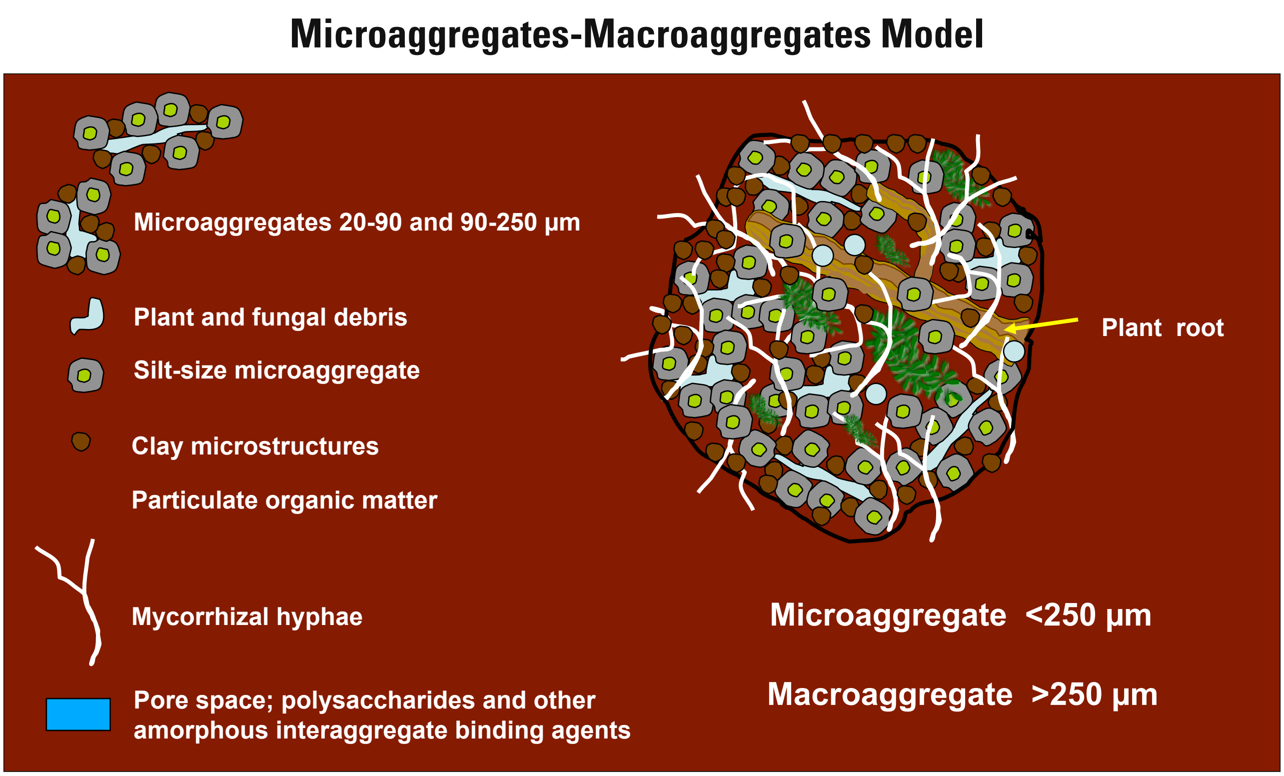

Figure 1. Dr. Charles Rice presentation adapted from Jastrow and Miller, 1997.

Macroaggregate Model and Hierarchy

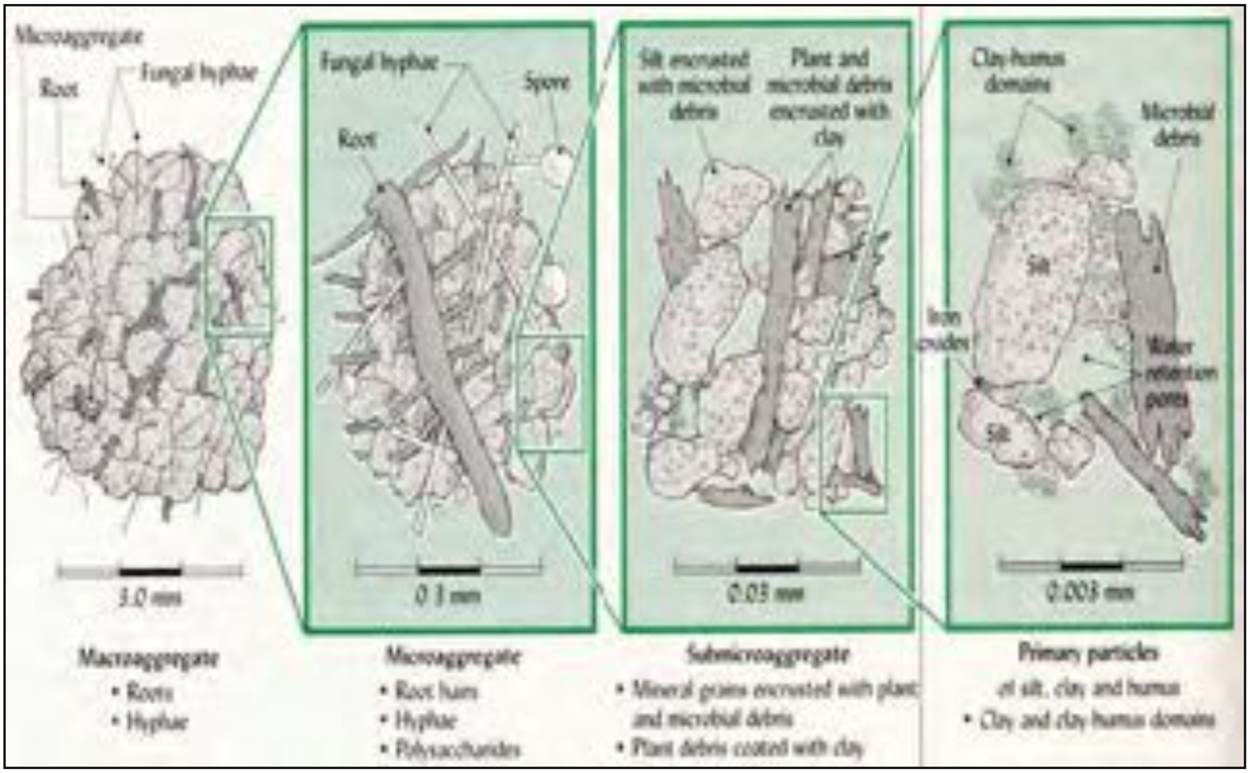

Figure 2. From Tisdall & Oades, 1982.

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

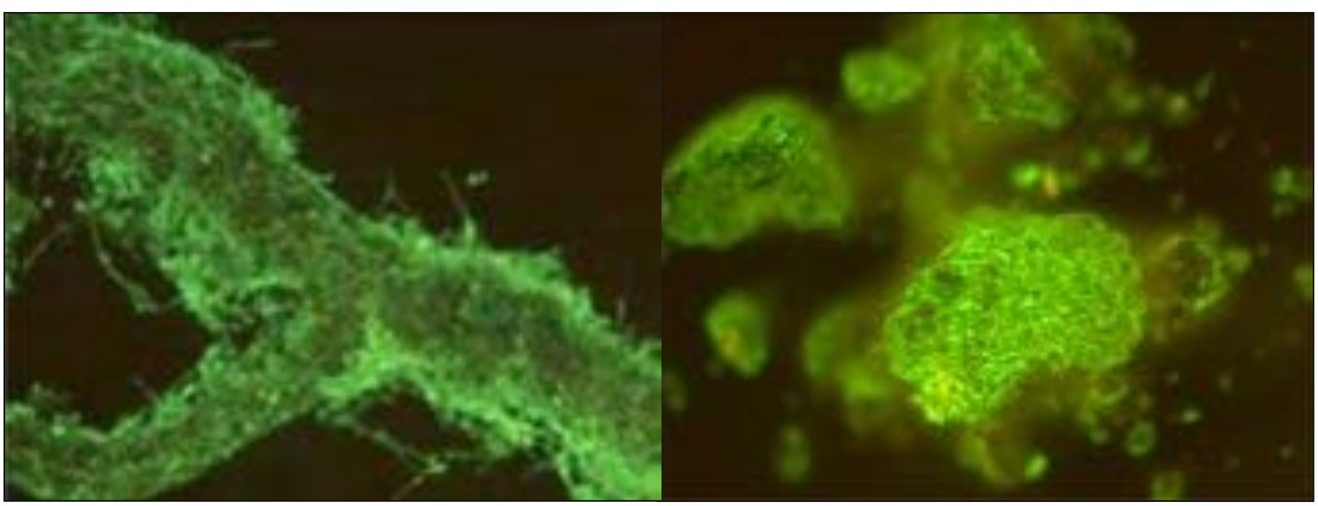

Figure 4. Glomalin surrounding a root heavily infected with mycorrhizal fungi and soil macroaggregates surrounded by glomalin. Photos by Dr. Sara Wright, USDA-ARS.

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

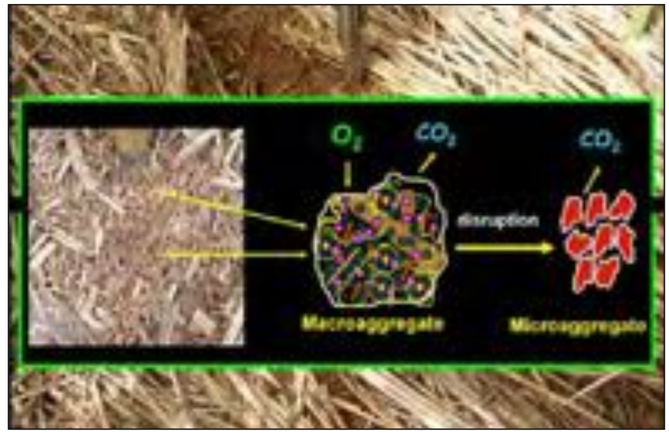

Figure 5. Tillage disrupts the macroaggregates and breaks them into microaggregates by letting in oxygen and releasing carbon dioxide. From Dr. João de Moraes Sá.

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

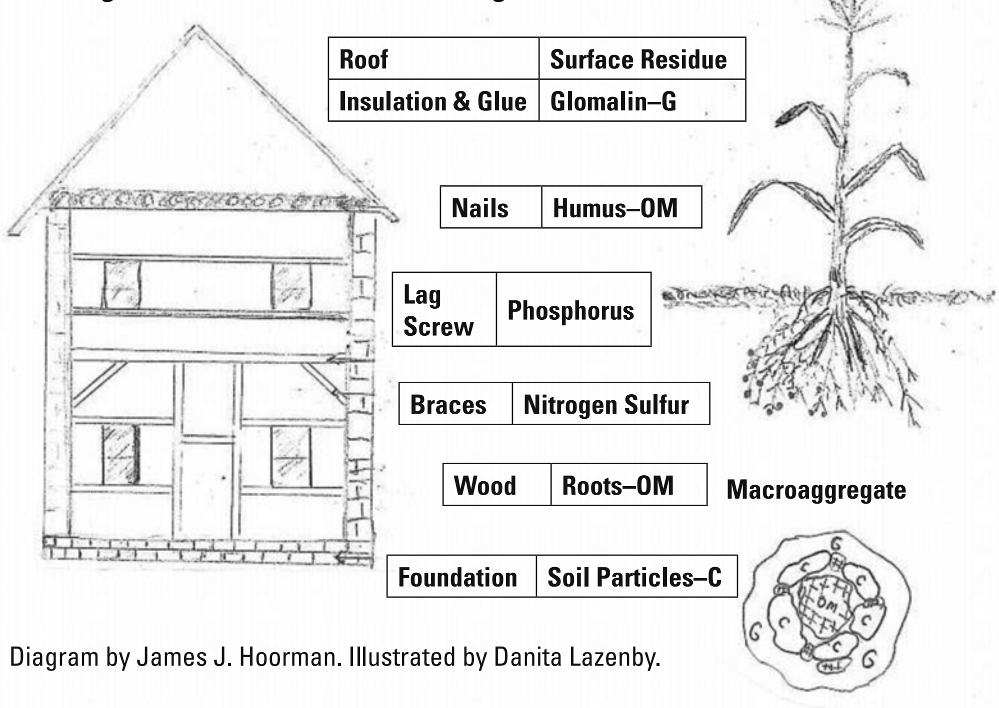

Diagram by James J. Hoorman. Illustrated by Danita Lazenby.

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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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.

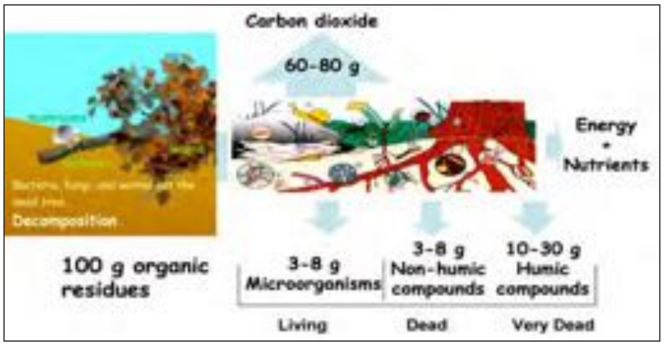


Diagram by Dr. Rafiq Islam

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.

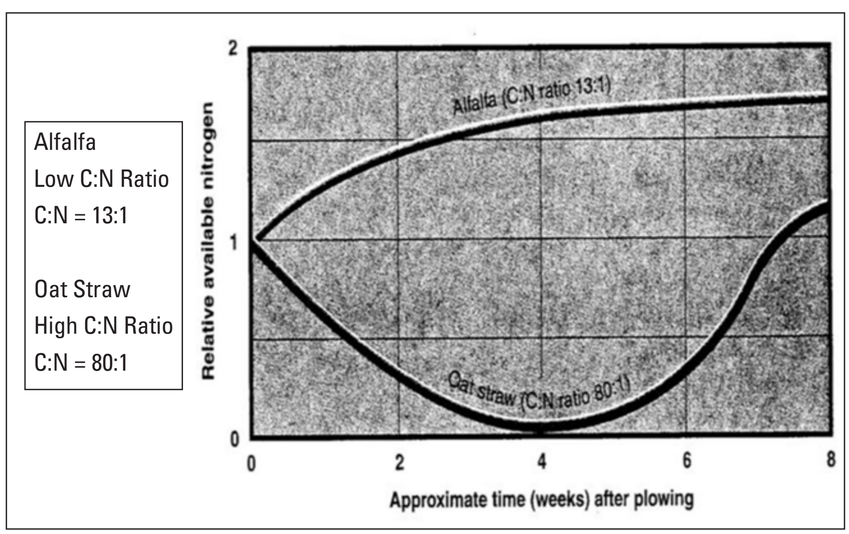
Carbon to Nitrogen Ratio

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



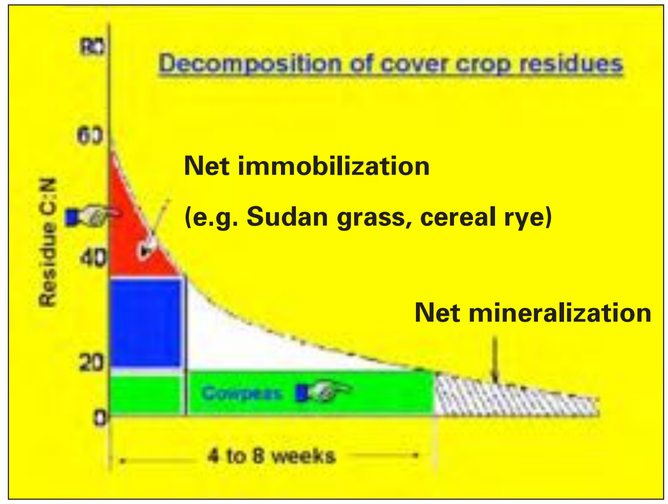
Graph of Relative Available N with Length of Time for Decomposition quickly. Bacteria are generally less efficient at converting organic carbon to new cells. Aerobic bacteria assimilate about 5 to 10 percent of the carbon while anaerobic bacteria only assimilate 2 to 5 percent, leaving behind many waste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

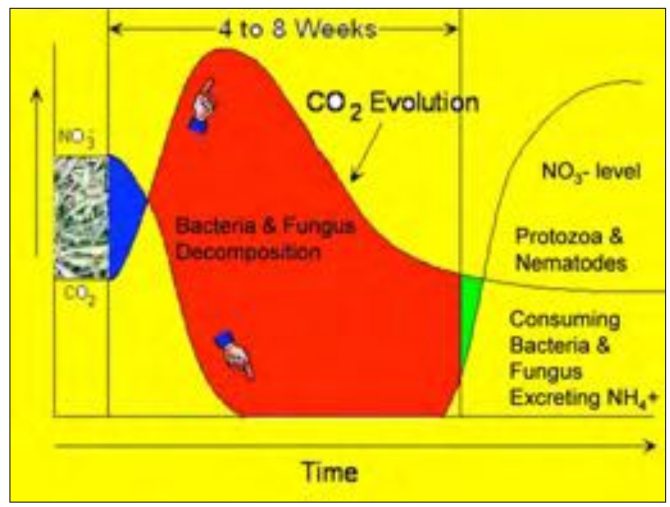
Mycorrhizal fungi live in the soil on the surface of or within plant roots. The fungi have a large surface area and help in the transport of mineral nutrients and water to the plants. The fungus life cycle is more complex and longer than bacteria. Fungi are not as hardy as bacteria, requiring a more 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.

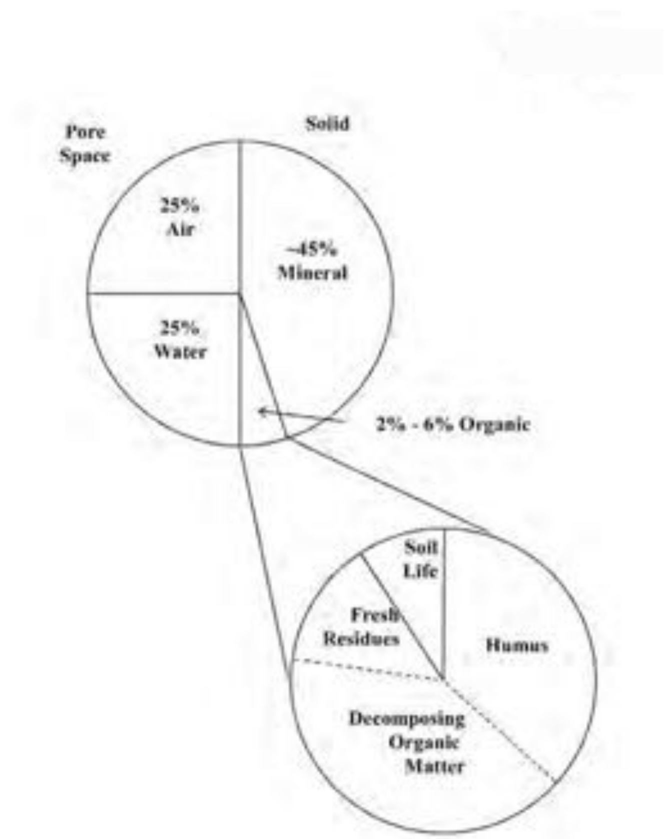

Figure 1. Approximate proportions of mineral matter, air and water-filled pore space, organic matter and living organisms in topsoil.

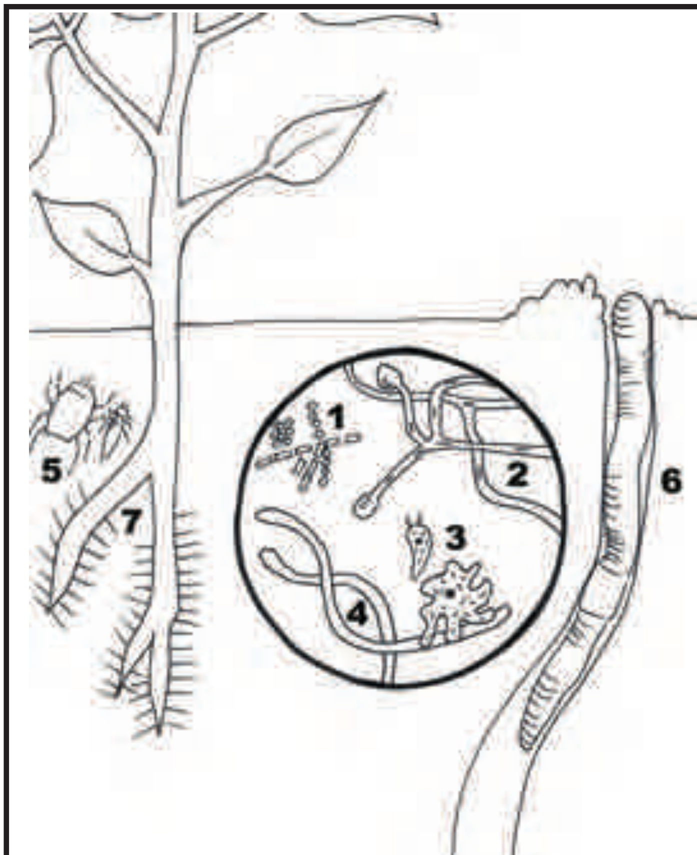

Figure 2. Main components of the soil life: (1) bacteria, (2) fungi, (3) protozoa, (4) nematodes, (5) mites, insects and other arthropods, (6) earthworms, and (7) plant roots.

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.

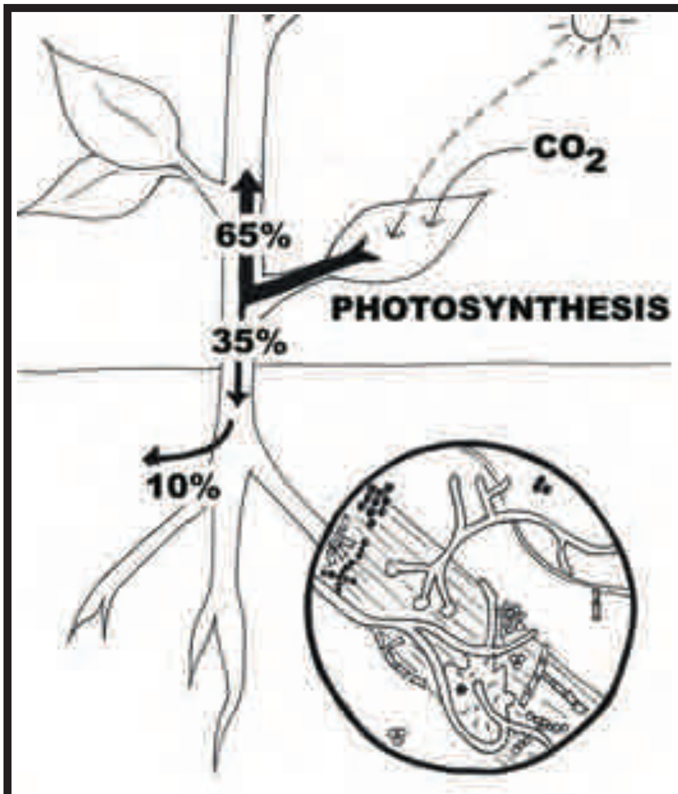

Figure 3. Plants release a significant portion of their annual photosynthetic product into the soil, supporting a vibrant microbial community in the root zone and forming a vital link between plant and soil.

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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