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Reducing Tillage Intensity in Organic Production Systems

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Contents

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This publication explores the different approaches to tillage intensity in organic crop production systems. It reviews a number of alternatives and provides a summary of recent research and future research needs.

A roller/crimper on a tractor being used to roll down a rye and hairy vetch cover crop. Photo: wikimedia

Introduction: Tillage and Agriculture

Tillage of the soil almost defines agriculture. In the first half of the 20th century, intensive tillage was such an integral part of mainstream American agriculture that no qualification or explanation was necessary. If you farmed, you plowed to break the sod, typically using either a moldboard or disc plow that inverted the soil cover, leaving virtually no plant material on the surface. This was usually followed by harrowing several times to create a seedbed, frequent cultivations to control weeds in the growing crop, and plowing again to bury residues and re-start the cycle.

As herbicide use became widespread, the importance of some tillage operations—especially post-planting weed cultivations—began to decline. Organic farmers, and others who chose not to use herbicides, continued to cultivate their crops using steel and cultural practices. However, one thing common to both the organic and non-organic farmers at mid-century was that both had a lot of bare soil between the seasons and between the rows.

Bare soil, whether left exposed by tillage or by herbicide, means potential for wind and water erosion, nutrient leaching, reduced biological diversity, soil hardpan development, loss of organic matter, and further challenges to the sustainability of farming. These downsides of intensive tillage were not so much denied as they were simply accepted as a necessary limitation of crop agriculture. Even to those concerned with conservation, other options were not readily apparent. This viewpoint began to change around 1960.

Inspired in part by Edward Faulkner's 1943 classic book *Plowman's Folly*—a critique of moldboard-plow tillage—researchers in the 1960s started taking a serious look at tillage alternatives that not only reduced the number of field operations but left a crop-residue mulch on the soil surface. Expectations were modest at first, but soon agronomists and farmers began envisioning productive cropping systems with a perpetual cover of living and/or decaying vegetation. With that sort of soil protection, much of the soil and environmental damage done by clean tillage might be halted and perhaps even reversed.

To visionaries of that era, herbicides and, eventually, genetically modified crops were the technological key to making such systems a reality. Herbicides had already made many cultivation operations appear to be less frequent and even obsolete in clean-tillage farming. It was logical to assume that they could be used to eliminate weed cultivation operations entirely. Today, a considerable body of low-till and no-till information and technologies has emerged, the bulk of it centering on the use of herbicides and genetically modified crops (Matheson et al., 2018).

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Tillage Practice Changes

Table 1 gives a general overview of trends in the tillage practices of farmers in the United States and changes from 2012 to 2017, as reported in the United States Census of Agriculture. The trend appears to suggest positive movement in the adoption of either reduced or no-tillage practices between 2012 and 2017. The definitions used by the National Agricultural Statistics Service (NASS) are a bit confusing, as both no-till and reduced tillage are categorized as a no-till practice, and it is suggested that the practice is done only for the purpose of weed control. Nonetheless, intensive tillage is still a significant practice, used on 25% of cropland in the U.S.

Table 1. Tillage Practice Changes. Source: USDA NASS, 2018

United States Tillage Practices: 2017 and 2012

	2012			2017		
	Farms	Acres	% of All Cropland*	Farms	Acres	% of All Cropland**
Cropland with No-Tillage Practices	278,290	96,476,496	31%	279,370	104,452,339	33%
Cropland with Reduced Tillage Practices	195,738	76,639,804	24%	217,069	97,753,854	31%
Cropland with Intensive Tillage Practices	405,692	105,707,971	34%	264,893	80,005,292	25%

*Total: 314,964,600 acres

**Total Harvested Croplands: 320,041,858 acres

Definitions:
No-till practices used: Using no-till or minimum till is a practice used for weed control and helps reduce weed-seed germination by not disturbing the soil.
Reduced tillage: Conserves the soil by reducing erosion and decreasing water pollution.
Intensive tillage: Refers to tillage operations that use standard practices for a specific location and crop to bury crop residues.

The Organic Approach to Tillage

Organic production systems include "the application of a set of cultural, biological, and mechanical practices that support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity. These include maintaining or enhancing soil and water quality; conserving wetlands, woodlands, and wildlife." (USDA Agricultural Marketing Service, 2015).

In certified organic production systems, the use of synthetic herbicides is prohibited. Alternative methods, of varying tillage intensity, are used for soil and weed control. A number of strategies have been developed and can be broadly described as a conservation tillage approach.

Making a conservation tillage approach work in organic production systems is not easy but offers several benefits, including the following:

- reduced wind and water erosion
- erodible land brought into production
- increased options for multiple cropping
- improved soil moisture management
- flexible timing for field operations
- improved soil structure
- improved soil health
- moderated soil temperature
- lower fuel and machinery repair costs because of fewer field passes

It is too often taken for granted that organic farming has been shackled to clean, deep, soil-inverted cultivation. This assumption has been and sometimes continues to be voiced to disparagingly characterize organic crop production as erosive and environmentally destructive and not sufficiently productive to meet global food demand (Kirchmann, 2019; Bergstrom and Kirchmann, 2016; Leifeld, 2012).

However, organic farmers have long nurtured an interest in conservation or lower-intensity tillage. This was well documented in the mid-1970s as part of the Washington University study of organic agriculture in the Corn Belt (Lockeretz et al., 1981). The researchers observed that the vast majority of organic farmers taking part in the study were using chisel plows rather than conventional moldboard plows. Chisel plowing is a form of mulch tillage, in which residues are mixed in the upper layers of the soil; a significant percentage remains on the soil surface to reduce erosion. Some organic growers had adopted ridge-tillage, another conservation tillage system with even greater potential to reduce erosion. The ready adoption of these practices stood in sharp contrast to neighboring conventional farms of that time, where there was, as yet, little to no evidence of conservation, lower-intensity tillage practices being implemented. Beginning in the 1990s, several researchers began work on no-till organic agriculture that continues to the present (Beach et al., 2018; Schonbeck et al., 2017; Lehnhoff et al., 2017; Creamer et al., 1995; Ashford and Reeves, 2003).

The remainder of this publication describes advances in conservation or reduced tillage intensity in organic farming, with an eye towards those used by organic farmers or with potential for greater use.

Chisel plow. Photo: YouTube – Collier & Miller Engineering

Disc harrow. Photo: Tractorpool.co.uk

Reduced Intensity Tillage Options

The following provides a description of the many options for reduced intensity tillage available to organic farmers.

Mulch Tillage

Mulch tillage is a system in which a significant portion of crop residue is left on the soil surface to reduce erosion. It is usually accomplished by substituting chisel plows, sweep cultivators, or disk harrows for the moldboard plow or disk plow in primary tillage. This change in implements is attractive to organic growers because residues are not buried deep in the soil, and good aerobic decomposition is thus encouraged. Of all the agronomic-scale options, mulch tillage is the most easily adapted to organic management and is appropriate for most agronomic and many horticultural crops.

Ridge and Strip Tillage

Ridge tillage is characterized by the maintenance of permanent or semi-permanent ridge beds across the entire field. Strip tillage is similar, but no ridges are formed. In general, the beds are established and maintained through the use of specialized cultivators and planters designed to work in heavy crop residues. In contrast to most forms of mulch tillage, more crop residue remains on the soil surface for a greater portion of the season. Additionally, when done on contour, ridge tillage can largely supplant the need for larger soil conservation structures, like terraces, on many fields. Like mulch tillage, ridge and strip tillage have proven quite adaptable to organic management, particularly with improvements in high-residue cultivation equipment.

High-residue cultivation equipment appears to be a key to making these tillage systems function successfully, by allowing cultivation through dense surface mulches. While there is considerable variation in equipment, the typical features of high-residue cultivators are large coulters, followed by large sweeps mounted on single shanks. The coulters cut through residue in the middle of the inter-row area to assure that the residue will not hang up on the sweep shanks. The sweeps are run shallow, yet deep enough so that the flow of soil helps carry crop residues over the sweep during cultivation. In the case of ridge tillage, furrowing wings are used on the sweep to aid in rebuilding ridges.

Killed-Mulch Systems

This system centers on the concept of growing a dense cover crop, killing it, and planting or transplanting into the residue. The dense biomass provided by the killed cover crop not only protects and builds the soil; it also provides substantial weed suppression. On smaller scales, organic farmers have long relied on dense mulches as an alternative to hoeing and cultivation for weed management. Killed-mulch systems are an attempt to capture the benefits of that practice on a larger scale.

In conventional conservation tillage, herbicides are primary tools for killing cover crops. The nonchemical alternatives being tried for organic systems include mechanical implements, as well as weather stress. The mechanical practices include mowing, undercutting, and rolling and crimping.

Ridge tillage. Photo: Monotec Monosem, South Africa

Strip tillage. Photo: Sugar Producer Magazine

Weather-Kill

The concept of weather-killing cover crops involves the strategic planting of a cover crop that will be reliably killed by temperature shifts as seasons change. Common strategies involve the planting of summer annual covers like forage sorghums, millet, cowpeas, buckwheat, berseem clover, hay beans, or annual medic that are easily killed by even mild winter freezes, while leaving a dense mulch. Planting or transplanting of early spring crops can follow after mowing and/or strip tillage.

One benefit of winter-kill systems is that they give farmers the option to plant an early spring cover crop or killed-mulch crop. Attempts to kill winter annuals at early growth stages have not worked well. More importantly, most winter annuals have not produced sufficient biomass by early spring to offer much weed suppression.

Winter-killed mulches cease transpiration as soon as they are killed. In dryer climates, this is an advantage, due to reduced soil-moisture depletion. In wetter climates, however, a living cover crop would help remove excess water and warm the soil to allow earlier field operations. Moisture conditions play an important role in the viability of a winter-kill system. A late-summer or early-fall drought can result in a poor cover crop going into the winter and far too little biomass for weed suppression.

Mowing

Several mowing technologies are in common use on mechanized farms. These include sickle bars, rotary (bushhog), flail, and disc mowers. Each has different characteristics that affect its utility in creating a suitable mulch.

Sickle bar mowers have been fairly effective. Sickles cut close to the soil surface, increasing the chances of a good kill; they also lay the cover down uniformly over the soil surface—an important characteristic in weed suppression. As a further advantage, sickle mowing does not chop up the cover crop. The major problem with this technology is encountered when mowing viney legumes like hairy vetch or field peas. The vines easily get hung up on the machine, slowing field operations and leaving a very uneven mulch.

Disc mowers do a good job of cutting viney crops and mow close to the soil surface. However, the resulting mulch layer is uneven, and bare strips are frequently left. Rotary mowing is perhaps the least suitable option. Rotary mowers do not cut as low as sickle bars. They distribute the mulch unevenly and chop it up, so that decomposition is rapid and soil coverage is short-term.

Flail mowing appears to be the preferred technology at present. It cuts low and leaves an even layer of residue. However, it also chops the biomass quite finely, leading to rapid breakdown and short-term coverage.

Timing is important when mowing. Rye is most effectively mow-killed at flowering. If mowing is done earlier, the plant re-grows readily. Optimum control of hairy vetch is managed when mowing is done at mid-bloom or later, though stem length appears to be a more important factor: the greater the stem length at mowing, the easier the kill.

Mowing has several advantages. It is less dependent on soil moisture conditions than other mechanical methods, like undercutting, that involve some tillage. Mowing can also be done at relatively fast field speeds and involves the use of commercially available equipment that requires little to no modification.

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Undercutting

Undercutting is not a new concept. V-blade field cultivators have long been used in the western states to control weeds for summer fallow by severing the plants below the crown and leaving the residue on the soil surface. They were especially popular in the 1940s and 1950s. There has been a resurgence in their use among organic growers since the late 1980s.

Undercutting entails the use of specialized equipment that both severs the roots of the cover crop and flattens the biomass on the surface of the soil. The unit is primarily suited to bed production systems. Originally designed by Nancy Creamer and fellow researchers at Ohio State, the undercutter features a large blade or blades (adapted from a V-blade plow) that are run just under the surface of the soil to cut cover crops off just below the crown. A rolling basket is positioned to the rear of the blades, both for depth adjustment and to flatten the severed cover crop.

The undercutter has proven successful in killing a variety of winter-annual cover crops, including rye, hairy vetch, bigflower vetch, crimson clover, barley, and subterranean clover. Kill was most effective when these were allowed to reach mid-bloom or later. Undercutting is much less successful at killing biennial and perennial species, such as red clover, ladino clover, sweet clover, fescue, orchard grass, and perennial ryegrass.

Undercutting is also effective for killing a variety of spring and summer annual cover crop species, including soybean, buckwheat, lentil, German foxtail millet, and Japanese millet, sesbania, and lablab. It is less successful with cowpeas, pearl millet, sudangrass, and sorghum-sudan grass.

Haybuster 3200 undercutter.
Photo: Parsons Equipment, Coulee, Washington

Noble undercutter.
Photo: Parsons Equipment, Coulee, Washington

A big advantage of the undercutter (and the V-blade) is that it achieves a good kill while not chopping the cover crop, resulting in a more persistent, weed-suppressive mulch. It also loosens the soil, which makes for easier transplanting. The undercutter is somewhat limited, however, if soil moisture levels are high. Soil type can also be a limitation.

Though the V-blade or Noble plow is still widely available in the West, bed-style undercutters are rarely commercially available and are often home-built.

Rolling and crimping is essentially mechanical lodging. Crimpers are used to bend or break the plant stems and press them uniformly against the soil surface. The kinds of equipment used for rolling and crimping are surprisingly varied. The most recognizable are field rollers; turf or construction rollers can also be used. A modified version of these basic rollers features angle-iron bars welded horizontally along the length of the roller, in a chevron pattern. This adds a crimping action for better kill. Similar rolling action can be achieved using cultipackers or comparable implements.

Rolling can also be done using a grain drill with closely spaced cutting coulters and cast-iron press wheels. In addition to lodging the crop, this implement also kills by cutting the cover crop stems and leaves. Another piece of equipment that has been employed with moderate success is a flail mower with the power disengaged. The roller gauge wheel apparently serves the purpose. One of the big advantages of rolling is that suitable equipment can usually be found on the farm and easily adapted.

Crimpers. Photo: No-till Farmer

Crimpers. Photo: BCS Tools

Roll-chopping involves the use of specialized equipment that is commercially available. Rolling stalk-choppers, such as those marketed under the trade name Buffalo, cut the cover crop stems perpendicular to the direction of travel. Roll-chopping has gained considerable visibility among no-till/low-till investigators. Several farmers have reported significant success, but stressed the need for a more flexible design to handle conditions like raised beds. A significant advantage of both rolling and roll-chopping is that they can be done at relatively fast field speeds.

Cover Crops for Killed Mulch Systems

In general, cover crop selection in killed mulch systems should favor dense, tall-growing species in wetter climates and water-use-efficient species in drier climates. In either case, the crop should be easily killed and leave considerable biomass. Research appears to concentrate most often on the winter annuals hairy vetch, grain rye, and winter peas. In this same category in northern climates is black medic—a short-lived perennial that reseeds itself annually. Where summer annuals are needed, research seems focused on soybeans, forage sorghums, and, to a lesser degree, on buckwheat.

Combining cover crop species—a legume with a grass—is often noted as a good strategy. In combination, nitrogen fixation from the legume can be optimized, a maximum level of biomass is usually produced, and the carbon-to-nitrogen ratio of the mulch is generally in a range that releases nitrogen to the crop at a desirable rate. In the case of winter cover crops, combinations are also desirable because harsh conditions may eliminate one of the species. In such instances, the survivor still succeeds in providing an acceptable level of soil protection.

Grain rye is of particular interest, due not only to its winter hardiness but also to its ability to generate biomass and its allelopathic characteristics. Rye produces chemicals that inhibit the germination and growth of a large number of broadleaf and grassy weeds. These chemicals, along with their breakdown products, continue to be active as rye residue decays on the soil surface, making rye an especially effective weed suppressant.

Rye is not the only cover crop with allelopathic characteristics; other grasses like oats also exhibit some allelopathy. Researchers have also investigated various brassica species, such as rape and mustard, though most have just looked into the effects of soil-incorporated residues. Although brassicas do provide some weed suppression through allelopathy, they will likely do best in combination with another cover crop capable of producing more biomass. It should be noted that allelopathy is a double-edged sword. Crops, too, can be damaged and researchers are working to determine which cover crops can be used safely with which cash crops.

The Challenges of Killed Mulches

Most killed mulches do not provide thorough, long-season weed control without some additional effort. For example, light can penetrate through them to the soil surface, even with the densest of killed mulches. Light penetration also increases as the mulch layer decomposes, and weeds can then begin to emerge. Thus, some form of hoeing, cultivation, or both may be needed later in the season.

In these circumstances, some farmers have tried high-residue cultivators. They report, however, that although they do work, they still "hang up" in especially heavy, viney mulches. Where weed problems are anticipated and relatively early cultivations are a certainty, a killed mulching system in which the biomass breaks down more rapidly may be desirable, in order to facilitate cultivation. This would suggest flail mowing, for example, combined with a legume or buckwheat cover crop that would decompose more rapidly.

One strategy used to improve stands is to shift from direct seeding to the use of transplants. Transplanting can be done somewhat later than direct seeding, allowing for greater warming of the soil. It also assures a better stand and allows the crop a more competitive jump on weeds. Transplanting is somewhat limited, however, as it is not appropriate for all crops and may require the use of a no-till transplanter.

Living-Mulch Systems

Living mulches represent another alternative to reduced intensity tillage in organic agriculture. In the broadest sense, the term "living mulch" can apply to any system in which an actively growing or dormant cover crop remains in place as a companion to a commercial crop. As such, this concept encompasses a number of practical and theoretical options. One of the approaches that

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has generated interest involves interseeding crops with low-growing smother crops that suppress weeds and reduce erosion both during the growing season and after the crop has been harvested. Another option is to interseed cover crops into the cash crop in the fall. Interseeding may eliminate one or more weed-controlling cultivations in an organic system. However, it is not a strategy to reduce primary tillage. Here, the focus is on living-mulch practices that involve the establishment of crops into living cover crops that are not killed, but remain living for all or part of the cropping season.

Erosion control and reduced tillage are among the main attractions that living mulches share with killed-mulch systems. Living-mulch systems also offer the specific benefit of insect pest suppression. Living mulches frequently serve as beneficial insect habitats, supporting a population of predators and parasites that help keep crop pest numbers at manageable levels.

Successful living-mulch systems strike a balance between weed suppression and competition with the cash crop for light, water, and nutrients.

Successful living-mulch systems strike a balance between weed suppression and competition with the cash crop for light, water, and nutrients. In a preferred system, the mulch would resume full dominance of the agroecosystem following harvest—crowding out weeds, preventing erosion, providing habitat, and building soil fertility. Achieving such an ideal can be highly challenging.

One of the more obvious strategies for making a living mulch system work entails supplementing cash-crop nutrition and moisture in a targeted way. Side dress and foliar fertilization strategies can be helpful here; especially promising is the use of drip fertigation, or supplying soluble organic fertilizers by injection into the irrigation system.

Cover Crop Selection for Living Mulches

A good living mulch has four desirable characteristics:

- Rapid establishment to provide early weed and erosion control
- Tolerance to field traffic
- Tolerance to drought and low fertility
- Low maintenance cost

These characteristics are considerably different from those desired for killed mulches, where tall, easily killed annuals typically predominate. Preferred living-mulch species are typically prostrate in growth habit and often perennial. Annual species, however, can also be effective choices, such as subterranean clover, or "subclover."

Subterranean clover is a self-seeding winter annual with a prostrate growth habit. Well adapted throughout much of the South, subclover is typically planted in late summer or fall. It grows vegetatively but is held dormant throughout much of the winter. Flowering and seed development occur in late spring and early summer. The plant then senesces and dies during the heat of summer, leaving a dense vegetative mulch that is non-competitive with the growing crop. The next generation of subclover arises from seed. Like the peanut, subclover is geocarpic, where the seed pod develops at and below the surface of the soil. This assures soil-to-seed contact and improves the chances for reviving the stand without tillage operations.

Living-Mulch Suppression

In instances where a cover crop like subterranean clover is used, some suppression is provided by the natural cycle of the plant itself as it senesces and dies, or goes into seasonal dormancy. Still, mowing can be beneficial, as previously pointed out. Most living mulches require some form of suppression during the cropping season. In conventional systems, it is not uncommon to use sublethal applications of herbicide for this purpose. Two mechanical means of suppression that are suited to organic systems are mowing and partial rototilling.

Mowing appears to be the most commonly used option on living mulch. Sometimes efforts are even made to collect the trimmed biomass and use it as an applied mulch on the cash crop.

Partial rototilling involves tilling the living mulch while leaving one or more strips of the cover crop to re-grow. This can be accomplished in a number of ways. Most tiller designs naturally leave a narrow strip of untilled soil. If this is inadequate, one or more sets of tiller tines can be removed. Partial rototilling has been used most successfully in stoloniferous cover crops like Dutch white and Ladino clover.

Livestock Suppression of Cover Crops

A final method of terminating living mulch cover crops that's considered here is to use intensive livestock grazing. The advantages of using livestock for cover crop termination include the following:

- Cause cover crops to release sugars (exudates), which builds soil humus.

- Cycle 70-80% of what they consume back to the soil in a form that directly feeds both microbes and plants.
- Add microbes from the rumen to the soil. These microbial species are similar to soil species of fungi, bacteria, beneficial nematodes, and protozoa—the workhorses of a functioning soil.
- Trample cover crops into soil for microbes to break down. This feeds microbe populations and cycles nutrients, including carbon, back into the soil.

One limitation is the possibility of soil compaction by livestock, but this can be limited by using high-intensity, short-duration grazing. Other limitations are that many crop farmers lack livestock to graze and that termination of the cover crop may not be complete (see ATTRA publication *Livestock as a Tool: Improving Soil Health, Boosting Crops*).

Current Research Efforts and Needs

The following provides a sampling of some current (2018 to 2020) research summaries on reduced tillage intensity in organic production systems.

General Research:

The Current State and Future Directions of Organic No-Till Farming with Cover Crops in Canada, with Case Study Support. 2018. By H.M. Beach, K.W. Laing, M. Van De Walle, and R.C. Martin. Sustainability. Vol. 10, No. 2.

A review of various factors to consider in the implementation of organic no-till in field and vegetable crop production. The study includes a review of research and description of two case studies of Canadian organic no-till farms. Summary conclusions include these:

- *Careful attention is required to what one means by organic no-till systems of production. Though no-till can be defined as the complete elimination of tillage in agriculture systems, in organic no-till (and non-organic), an improved definition would be systems that include patterns over time of no-till and tillage, or what the authors call rotational no-till farming.*
- *Cover crops are the essential tool for organic weed management.*
- *Cover crop establishment is a critical factor to cash-crop success.*
- *The impacts of timing and method of cover crop termination are critical to cash-crop success.*
- *Types and mixes of cover crop varieties have important soil nutrient impacts.*
- *More research is needed on: 1) cover crop management to suppress weeds; 2) balancing mulch coverage with the need to supply nutrients and light to cash crops; and 3) development of machinery suitable to work with thick mulches.*

Knowledge Gaps in Organic Research: Understanding Interactions of Cover Crops and Tillage for Weed Control and Soil Health. 2020. By W.R. Osterholz, S.W. Culman, C. Herms, F.J. de Oliveira, A. Robinson, and D. Doohan. Organic Agriculture. June 12.

A review of current research literature. The researchers suggest more work to understand these issues:

- *Impact of using cover crops and varying organic tillage methods on soil health and weed control.*
- *Newer soil health indicators to determine soil health impacts.*
- *Longer-term results.*

Reduced Tillage Intensity in Field Crops

Grain Yield and Quality of Organic Crops Grown under Reduced Tillage and Diversified Sequences. 2019. By M.R. Fernandez, R.P. Zenter, M.P. Schellnberg, J.Y. Lesson, O. Aladenoia, B.G. McConkey, and M. Saint Luce. Agronomy Journal. Vol. 11, No. 2.

A Canadian-based (Saskatoon) organic field trial examining yield relationships between tillage intensity in a simple rotation (wheat, green manure) and a diversified rotation (wheat, oilseed/pulse, green manure). The core ideas include these:

- *Yield variation was explained more by precipitation and soil nitrate levels than by weed infestations.*
- *Wheat yields were higher under high-then-low tillage, as well as in the simplified, rather than the diversified, rotation.*
- *Protein concentration in wheat grain varied among years, and there was no negative association with yield.*
- *Based on observations in the wet years during which this trial was conducted, the low-tillage treatment did not appear to be viable for more than a few years.*

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Agronomic and Economic Tradeoffs between Alternative Cover Crop and Organic Soybean Sequences. 2019. By R.J. Champagne, J. M. Wallace, W.S. Curran, and B. Baraibar. Renewable Agriculture and Food Systems. December 2.

This three-year (2015-2017) research effort explored alternative strategies for reducing tillage frequency and intensity for various cropping and cover-crop sequences (rotations), including corn, soybeans, and spelt. Major results include the following:

- *Tillage-based soybean production marginally increased grain yield compared with reduced-tillage soybean production.*
- *Soybean stand establishment and weed biomass were the primary drivers of yield variability.*
- *The reduced-tillage soybean sequence (rotation) resulted in 50% less soil disturbance compared to tillage-based soybean sequence (rotation).*
- *Reduced-tillage soybean sequence (rotation) resulted in lower input costs than the tillage-based soybean sequence (rotation), but was less profitable because of lower yields.*

Reduced Tillage Intensity in Vegetable Crops:

Weed Functional Diversity as Affected by Agroecological Service Crops and No-Till in a Mediterranean Organic Vegetable System. 2020. By C. Ciaccia, L. Armengot Martinez, E. Testani, F. Leteo, G. Campanelli, and A. Trinchera. Plants. Vol. 9, No. 6.

A two-year study done in Italy, looking at four different cereal Agroecological Service Crops (ASC) (defined as catch crops, cover crops, or green manures) in relation to low tillage intensity in vegetable systems. Key findings:

- *All ASC crops demonstrated strong weed suppression with little variation between the four types examined.*
- *All ASC crops had late flowering and wider flowering spans, which lessens weed dispersal and attracts beneficial insects.*
- *Using in-line roller crimpers for cover-crop termination needs to also be incorporated with other soil-management practices.*

Tarps to Terminate Cover Crops before No-Till Organic Vegetables. 2019. By C. Strader, C. Hartnett, and J. Dawson. University of Wisconsin-Madison Extension, Dane County Extension.

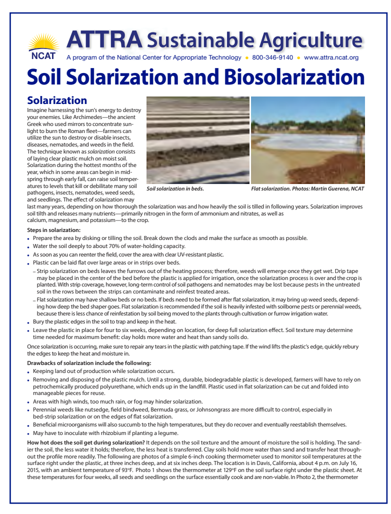
A one-year (2017-2018) trial of using tarps (silage tarp and landscape fabric) to terminate cover crops in organic vegetable crop systems. Key findings:

- *Silage tarps and landscape fabric terminated rye/vetch cover crop fully in three weeks.*
- *Brussels sprout yields were the same for all the no-till treatments and conventionally tilled control.*
- *A good stand of rye is critical for creating a weed-smothering mulch layer.*
- *Labor was significantly higher for the tarped no-till treatments in this trial because of the hand-labor required for planting, due to insufficient cover crop biomass to prevent weeds.*

Scale and Lower-Intensity Tillage: Tarps, Soil Solarization, and Biosolarization

The scale of a farming operation can play a role in what is possible in lowering tillage intensity in organic production systems, as in the case of the use of tarps to terminate cover crops. Clearly, it would be difficult, if not cost-prohibitive, to use such a system across hundreds of acres. Another related technique, similar to tarps, is what is called *soil solarization* and *biosoliarization*.

Soil solarization, while not a short-term tillage reduction method, is done by laying clear plastic over previously tilled soil during the hotter months of the year. By raising soil temperatures to levels that destroy or handicap soil pathogens, insects, and weed seeds and seedlings, future tillage may be minimized. The downside is that this ground is kept out of production during the solarization period that can last four to six weeks. Biosolarization combines soil solarization with anaerobic soil disinfestation (ASD). This is basically a kind of in-place composting of organic matter. With biosolarization, the plastic covering is in place for a shorter period of time (five to nine days) and helps with improving soil quality with added biomass. See the ATTRA publication *Soil Solarization and Biosolarization.*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Soil Solarization and Biosolarization

Solarization

Imagine harnessing the sun's energy to destroy your enemies. Like Archimedes—the ancient Greek who used mirrors to concentrate sunlight to burn the Roman fleet—farmers can utilize the sun to destroy or disable insects, diseases, nematodes, and weeds in the field. The technique known as *solarization* consists of laying clear plastic mulch on moist soil. Solarization during the hottest months of the year, which in some areas can begin in mid-spring through early fall, can raise soil temperatures to levels that kill or debilitate many soil pathogens, insects, nematodes, weed seeds, and seedlings. The effect of solarization may last many years, depending on how thorough the solarization was and how heavily the soil is tilled in following years. Solarization improves soil tilth and releases many nutrients—primarily nitrogen in the form of ammonium and nitrates, as well as calcium, magnesium, and potassium—to the crop.

Soil solarization in beds. *Flat solarization. Photos: Martin Guerena, NCAT*

Steps in solarization:

- Prepare the area by disking or tilling the soil. Break down the clods and make the surface as smooth as possible.
- Water the soil deeply to about 70% of water-holding capacity.
- As soon as you can reenter the field, cover the area with clear UV-resistant plastic.
- Plastic can be laid flat over large areas or in strips over beds.
  - Strip solarization on beds leaves the furrows out of the heating process; therefore, weeds will emerge once they get wet. Drip tape may be placed in the center of the bed before the plastic is applied for irrigation, once the solarization process is over and the crop is planted. With strip coverage, however, long-term control of soil pathogens and nematodes may be lost because pests in the untreated soil in the rows between the strips can contaminate and reinfest treated areas.
  - Flat solarization may have shallow beds or no beds. If beds need to be formed after flat solarization, it may bring up weed seeds, depending how deep the bed shaper goes. Flat solarization is recommended if the soil is heavily infested with soilborne pests or perennial weeds, because there is less chance of reinfestation by soil being moved to the plants through cultivation or furrow irrigation water.
- Bury the plastic edges in the soil to trap and keep in the heat.
- Leave the plastic in place for four to six weeks, depending on location, for deep full solarization effect. Soil texture may determine time needed for maximum benefit: clay holds more water and heat than sandy soils do.

Once solarization is occurring, make sure to repair any tears in the plastic with patching tape. If the wind lifts the plastic's edge, quickly rebury the edges to keep the heat and moisture in.

Drawbacks of solarization include the following:

- Keeping land out of production while solarization occurs.
- Removing and disposing of the plastic mulch. Until a strong, durable, biodegradable plastic is developed, farmers will have to rely on petrochemically produced polyurethane, which ends up in the landfill. Plastic used in flat solarization can be cut and folded into manageable pieces for reuse.
- Areas with high winds, too much rain, or fog may hinder solarization.
- Perennial weeds like nutsedge, field bindweed, Bermuda grass, or Johnsongrass are more difficult to control, especially in bed-strip solarization or on the edges of flat solarization.
- Beneficial microorganisms will also succumb to the high temperatures, but they do recover and eventually reestablish themselves.
- May have to inoculate with rhizobium if planting a legume.

How hot does the soil get during solarization? It depends on the soil texture and the amount of moisture the soil is holding. The sandier the soil, the less water it holds; therefore, the less heat is transferred. Clay soils hold more water than sand and transfer heat throughout the profile more readily. The following are photos of a simple 6-inch cooking thermometer used to monitor soil temperatures at the surface right under the plastic, at three inches deep, and at six inches deep. The location is in Davis, California, about 4 p.m. on July 16, 2015, with an ambient temperature of 93°F. Photo 1 shows the thermometer at 129°F on the soil surface right under the plastic sheet. At these temperatures for four weeks, all seeds and seedlings on the surface essentially cook and are non-viable. In Photo 2, the thermometer

Conclusions: Beyond Tillage

It seems unlikely that any system of agriculture production, organic or not, will ever accomplish the complete elimination of tillage. Perhaps a more relevant question posed by recent researchers is: how little tillage is "no-till?" (Beach et al., 2018). If complete elimination of tillage is not achievable, then greater attention needs to be placed on what level of tillage intensity is needed for both the economic and productivity needs of famers. Making cover crops pay is a topic that has been of wide interest in the research and farming communities (SARE, 2007; Groff, 2020).

An example of the need for this focus is the current situation of non-organic, no-till field-crop farmers in Montana who are experiencing increasing soil acidification leading to complete crop losses across large parts of their farms. This acidification is due to a long history of applying greater amounts of synthetic fertilizers than the crop can uptake. Over time, this has led to buildup of those fertilizers in the top few inches of the soil profile (known as *pH stratification*), due to the lack of tillage. The acidification cause soil pH to become so low that metals in the soils, like aluminum and manganese, become more soluble, stunting root and shoot growth. The irony is that part of the solution to this problem—besides more careful application of synthetic fertilizers—is to till these fields to break this pH stratification, as well as to integrate greater diversity of deeper-rooted crops into more complex crop rotations (Jones et al., 2019.).

Organic production systems at their best exemplify a complex system of practices, of which tillage is but one important element. Understanding how to lower the intensity of tillage in organic agriculture production is an important objective, but tillage alone is not sufficient to create resilient, long-term agro-ecologically sustainable systems of production.

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Further Resources

Organic Grain Resource and Information Network (OGRAIN)

www.uworganic.wisc.edu/ograin

Virtual research-farm tours. Short videos of ongoing efforts at no-till and reduced tillage in organic field-crop production systems. Titles include the following:

- Rolled Crimped Organic Soybeans
- Cultivating Organic Soybeans
- Reduced Tillage in Organic Corn
- Roller Crimped Soybeans
- Cultivated Organic Soybeans
- Spring Seeded Cereal Rye with Soybeans

Reduced Tillage in Vegetables Project, Cornell Small Farms Program

https://smallfarms.cornell.edu/projects/reduced-tillage

Project resources include farm stories, webinars, and details on building permanent bed systems, how to do strip tillage, and tarping.

Organic No-till Resources, Rodale Institute

https://rodaleinstitute.org/why-organic/organic-farming-practices/organic-no-till

Introduction to organic no-till farming, with particular emphasis on roller crimpers, and other educational materials.

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