Use of black polyethylene tarps to advance reduced tillage system for organic beets

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Horticulture

by

Haley Rebekah Rylander

August 2019

ABSTRACT

Organic vegetable farmers rely on intensive tillage to control weeds, incorporate amendments and residues, and prepare seedbeds. Intensive tillage, however, can lead to a decrease in long-term soil health. The use of black, impermeable, polyethylene tarps on the soil surface prior to planting reduces weed pressure, increases crop yield, and preserves prepared soil for several weeks. Cultivar Boro beets were planted at three sites (Freeville, NY, Riverhead, NY, Monmouth, ME), two years (2017 and 2018), on two dates (May and June). Tarps were applied and left in place for three time periods prior to projected planting dates: 1) either overwinter (early planting) or 10+ weeks (late planting), 2) 6-8 weeks, 3) 3-5 weeks, and 4) no tarp. After tarp removal, plots were tilled to 4-8 in. (conventional till), 1-3 in. (reduced till), or left undisturbed (no-till), then direct-seeded with beets. Soil environment, weed pressure, and crop yield were measured at pre- and post-tarp removal, midseason, and at harvest. Tarp use increased soil moisture and nitrate concentrations and increased soil temperature by 1-3°C compared with bare ground at the time of tarp removal. Tarps did not decrease crop residue percent cover compared with bare ground. Tarp use of three or more weeks reduced weed percent cover by 95-100% at the time of tarp removal and retained lower weed pressure for 10 days in most site years. Tarp use increased crop yield and decreased the impact of tillage treatments for weed biomass and crop yield, making reduced tillage a more viable option in organic vegetable systems.

BIOGRAPHICAL SKETCH

Haley Rylander is from Sherman, Texas and received her Bachelor of Science in Environmental Science from the John V. Roach Honors College at Texas Christian University in Fort Worth, Texas. As a part of her bachelor's degree, she also studied at the University of Canterbury in Christchurch, New Zealand.

ACKNOWLEDGEMENTS

I would like to thank my Committee Chair, Anu Rangarajan, for her support of my research, writing, and ambitions both academic and otherwise. She has truly been inspiring and gone above and beyond for me. Thank you to my Committee members, Toni DiTommaso and Mark Hutton, for their input, critique, and encouragement. I would also like to thank Ryan Maher and Brian Caldwell for helping in all aspects of this project, from experimental design to handling machinery and helping organize data.

This work was supported by the OREI Program (2014-51300-22244) and Smith Lever/Hatch Federal Capacity Funding (2017-18-122) from the USDA National Institute of Food and Agriculture, as well as the Toward Sustainability Foundation 2017/18.

TABLE OF CONTENTS

Chapter 1: Literature Review

Part I: Conservation tillage and use of plastic in organic agriculture

Tillage is a farming method nearly as old as agriculture itself. The primary function of tillage is to create suitable planting conditions by loosening and smoothing the soil surface. The moldboard plows of ancient civilizations morphed over centuries to steel plows in the industrial revolution and finally to the myriad of specialized and mechanical tillage implements of today. Tillage serves to mechanically control weeds, insects, and diseases, and to incorporate fertilizers and pesticides.

Frequent intensive tillage, however, can degrade soil quality by breaking soil aggregates, increasing soil compaction and erosion, and contributing to loss of soil moisture and organic matter. Tillage costs labor, fuel, and time for every pass in a field, and requires investment in and maintenance of equipment. Reducing tillage can cut fuel use by two-thirds compared with conventional tillage (Trewavas, 2004). Reducing tillage benefits soil health, conserves fuel and energy use, and can reduce costs on a farm provided weeds and pests are controlled and yields maintained.

Tillage also impacts global carbon cycles. Intensive tillage releases CO_2 into the atmosphere by encouraging soil drainage and aeration, thereby speeding soil warming and increasing organic carbon mineralization by microorganism respiration (Reicosky, 1997; Silva-Olaya et al., 2013). In 1970, following decades of widespread tillage, agriculture in the United States was a carbon source. By the 1980s, as farmers reduced, replaced, or discontinued their use of the moldboard plow, agriculture became a sink for carbon (Allmaras et al., 2000). In 2017, over 60% of cropland in the U.S. was under conservation tillage, and approximately 50% is predicted to be under no-till within the next two decades (Tidale et al., 2017).

Tillage Definitions and Strategies

There are three types of tillage events: primary tillage, secondary tillage, and cultivation. Primary tillage is the initial operation used to break-up the soil surface and bury weeds, seeds, and residue. Secondary tillage is any operation following primary tillage that further fractures and levels the soil surface and prepares the seedbed for planting. Cultivation is any operation used to remove weeds after planting (DiTommaso, 2017). There are three levels of tillage intensity as defined by the depth and width of soil disturbance and the amount of residue remaining on the soil surface following tillage - intensive, reduced and conservation (Table 1). Numerous methods of tillage (eg. no till, vertical till, strip-till, ridge-till, mulch-till) fall under each of these levels (Table 1), and each method uses specialized equipment to perform primary tillage, secondary tillage, or cultivation (Table 2).

Table 1. Tillage defined by levels of intensity and method of soil disturbance compared between two voices of authority in the agricultural industry: the American Society of Agricultural Engineers (ASAE), and the Conservation Technology

	Levels of Tillage Intensity ASAE[y]	CTIC[z]
Intensive	<15% residue	<15% residue Full-width, 1-15 passes
Reduced	15-30% residue	15-30% residue Full-width
Conservation	>30% residue	>30% residue

	Tillage Systems ASAE	CTIC
No-till	Disturbance limited to strips in previously undisturbed soil No more than 1/3 row width	Disturb minimum amount of soil needed for good stand and yield
Vertical/Direct seed/Slot	Crops grown in narrow slots Disturbance limited to fertilizer/seed placement <2/3 row width	*Considered no till* Narrow ripper (12-14 in deep) causing little surface disturbance, usually in Fall
Strip-till	Crops in narrow tilled strips Disturb no more than 1/3 row	*Considered no-till* Strip ~10in wide x 4-5 in deep in fall; plant into in spring
Ridge-till	Pre-formed ridges with crop residue in furrows After planting, ridges rebuilt by cultivation Less than 1/3 row disturbance	Build 4-6-in high ridges; scrape off 1-2 in during planting
Mulch-till	Full-width till that maintains plant residue on surface year-round	Full-width till with chisel plow, disk, cultivators, etc.

[y] American Society of Agricultural Engineers, 2005
[z] Conservation Technology Information Center, 2004

Information Center (CTIC).

Table 2. Common tillage implements with associated tillage event, depth of soil disturbance, method of soil disturbance, and amount of residue and weed suppression.

	Tillage[z]	Depth[z]	Mechanism[z]	Residue and Weeds[z]
Moldboard Plow	Primary	12-18 in deep 12-18 in wide	Inverts soil; no mixing	Completely buries residue, weeds, etc.
Chisel Plow	Primary	Depth varies	Breaks plow layer, loosens soil; little mixing	Leaves most residue on surface
Subsoiler	Primary	18 in deep	Rip deep channels for drainage and aeration	Leaves most residue on surface
Rototiller	Primary Secondary	Depth varies 30 in-8 ft wide	Cuts, breaks, and mixes soil	Mixes and incorporates residue into soil
Spading Machine	Primary Secondary	Depth varies	Mixes soil without compaction or inversion	Mixes and incorporates residue into soil
Disk	Primary Secondary	Depth varies, disk size varies	Chop and mix soil	Can incorporate residue and amendments
Harrow	Secondary Cultivation	Shallow – a few inches	Smooths plowed soil and breaks up soil clods	Prepares shallow seedbed, incorporates light residue, kills small weeds
Field Cultivator	Secondary Cultivation	Shallow – a few inches	Smooths plowed soil and breaks up soil clods	Prepares shallow seedbed, incorporates more robust residue, kills small weeds
Bed Former	Secondary	Beds 4-12 in high and 2-5 ft wide	Push and flatten soil into raised beds	

[z]Definitions and descriptions referenced from Grubinger, 1999, and American Society of Agricultural Engineers, 2005

Reduced Tillage and Soil Structure: Bulk Density

Bulk density is the dry weight of a soil in a given volume. Soil bulk density is an indicator of compaction, and is affected by soil texture, organic matter content, and root penetration (U.S. Department of Agriculture Natural Resources Conservation Service, 2008). The effects of tillage on soil bulk density are complex and influenced by time, previous soil management, and soil type. Bulk density may require a period of four or more years' transition from conventional tillage to decrease under no-till management (Coorhees and Lindstrom, 1984).

Increased organic matter associated with no-till contributes to lower bulk density, and supports more stable soil aggregates and pore space (Franzluebbers, 2002) but compaction from tractor and machinery traffic and poor aggregate stability from previous management can cause high bulk density in reduced tillage soils. In soils managed with no-till for just a few years, bulk density in the top 5-10 cm of soil is higher in no-till soils as compared with tilled soils (Angers et al., 1997; Cavalaris and Gemtos, 2002; Hill, 1990; Tebrügge and Düring, 1999).

When soil is no longer loosened by mechanical means, it takes time for the structural stability of soil to improve after switching to reduced tillage. Soil bulk density of silty clay loam in Minnesota decreases in no-till soil as compared with tilled soil after four years of management, although bulk density is higher in no-till soil the first two years and similar to conventional-till at four years (Voorhees and Lindstrom, 1984). Longer-term no-till management (10-25 years) has conflicting results on soil bulk density. In silt loam and sandy loam soils managed under no-till for 10 years, there is no difference in bulk density between no-till and conventional-till systems at different depths (Arshad et al., 1999; Blevins et al., 1982).

More commonly, bulk density is influenced by soil depth in no-till systems. Bulk density is not influenced by tillage compared with no-till when samples from the top 60 cm of soil are averaged across depths (Angers et al., 1997). Sandy loam soils in Switzerland have higher bulk density in no-till systems compared with conventional-till systems in the topsoil (0-10 cm), but similar bulk density in the subsoil (10-40 cm) after 20 years (Martínez et al., 2016). Similarly, silt loam soils in Germany have higher bulk density in no-till soils in the top 28 cm of soil, and similar bulk densities between tillage systems below 28 cm after 25 years (Schlüter et al., 2018). Bulk density of no-till soil compared with harrowed and cultivated soil is higher at 15 cm, lower at 20 cm, and similar below 25 cm, showing that no-till management loosens the layer of compaction caused by plowing after 15 years (Singh et al., 2014).

Reduced Tillage and Soil Structure: Aggregates

Soil aggregates are soil particles bound to each other by soil texture, ions, organic functional groups, and organic compounds and mycelia formed by microorganisms. Aggregate stability is the measure of the ability of soil aggregates to remain bound together when disturbed. Good aggregate stability facilitates plant root growth and the movement of water and air through the soil. It also prevents individual soil particles on the soil surface from breaking free of aggregates and clogging surface pores, which creates a seal against water, air, and emerging seedlings (crusting) (U.S. Department of Agriculture Natural Resources Conservation Service, 1996).

Frequent tillage disrupts soil aggregates by physically agitating the soil with tillage implements and forcing bound soil particles apart. Aggregate stability is enhanced by increasing soil organic matter content, reducing soil disturbance, and keeping soil covered with crops, cover crops, or sod, which encourage pore development.

Microbial activity increases aggregate stability (Gupta and Germida, 1988; Kandeler and Murer, 1993; Roberson et al., 1991). No-till soils have higher microbial activity than conventionally tilled soil (Hungria et al., 2009; Tebrügge and Düring, 1999; Wang et al., 2014). Mycelia and hyphae promote polysaccharide-mediated binding and the formation of macro aggregates. No-till soils can accommodate up to 1.46x and 3x higher mycelia and fungal hyphae respectively compared to conventionally tilled soils in the top 5 cm of soil (Beare et al., 1997).

Reduced Tillage and Soil Water: Water Holding Capacity

Water holding capacity is the ability of a soil to retain water in pore spaces plus that bound to soil particles by hydrogen bonding. Soil with a high water holding capacity reaches saturation more slowly than soil with low water capacity, which can slow leaching of nutrients through the soil profile. High water holding capacity also makes water more available to plants and provides resilience against drought.

Soil texture, organic matter content, pore space size, and compaction affect water holding capacity (Gardiner and Miller, 2008). Smaller poor space retains water more efficiently by capillary action, thereby slowing drainage. Water drains through large pores by gravitational flow. Fine-textured soils have greater water holding capacity than course-textured soils due to smaller pore spaces. High organic matter content in soil results in greater water retention by encouraging sticky aggregate formation and holding water through adhesive and cohesive forces in the soil (Food and Agriculture Organization of the United Nations, 2005; Hudson, 1994). Compaction caused by tillage breaks soil aggregates and can form an impermeable barrier in the soil, decreasing water holding capacity.

Water holding capacity of a variety of silt loam, sandy loam, and silty clay loam soil is greater in no-till soil than in tilled soil (Franzluebbers, 2002; Hill et al., 1985; Johnson and Hoyt, 1999; Mendoza et al., 2008; Power et al., 1986; TerAvest et al., 2015). The clayey Piedmont soils in the Southeast have greater water retention in conventional-till soils than in no-till soils in the top 30 cm of soil, but no difference below 30 cm (Tollner et al., 1984). This may be due to the small pore size of clay soils. No-till soils have more micropores (<0.75 mm) and fewer macropores (>15 mm) compared with tilled soils (Arshad et al., 1999; Dörner and Horn, 2009; Hill et al., 1985). If pore space is already small, such as in clayey soils, the effect of no-till on water holding capacity may be reduced.

No-till soils have reduced surface evaporation compared with tilled soils (Hill et al., 1985, Johnson and Hoyt, 1999). While soil water holding capacity is not influenced by surface evaporation, crop residue left on the surface provides protection against air contact and wind, preserving moisture already present in the soil.

Reduced Tillage and Soil Water: Water infiltration

Water infiltration is the measure of the movement of water through the upper layers of soil. Pore size, soil texture, aggregate size, percent organic matter, soil temperature, and compaction affect soil water infiltration. As soil becomes wetter, water infiltration decreases (Gardiner and Miller, 2008). High water infiltration creates well-drained soils and prevents water-logging and anaerobic conditions.

Water infiltration can increase up to three times under no-till systems compared to tilled systems (Franzluebbers, 2002). Water infiltration is increased in reduced-till systems by improved aggregate stability, which provides larger pore space extending deeper in the soil profile, and higher organic matter content, which lowers bulk density and allows water to move through the soil more easily. Increased populations of organisms such as earthworms also create pore space and channels. The reduced soil disturbance of no-till and reduced-till results in higher populations of many earthworm species (Crittenden and de Goede, 2016; Drakopoulos et al., 2018; Fox et al., 2017). Soil drainage due to earthworm activity increases in reduced-till compared with conventional-till (Trewavas, 2004).

Reduced Tillage and Soil Temperature

Soil managed with no-till has decreased surface temperature compared to conventionally tilled soil in the top 15 cm of soil (Johnson and Lowery, 1985; Tollner et al., 1984). Soil managed with strip tillage has lower surface temperature than conventionally tilled soil, although sometimes soil temperatures are slightly higher than no-till soil (Jokela and Nair, 2016). Crop residue left in place by reduced tillage can decrease soil temperature by at least 5°C at a 5 cm depth (Power et al., 1986; Tollner et al., 1984).

Inversion and mixing by tillage exposes soil to warm air, increasing the temperature of the soil. Warmer soil absorbs water more quickly than cooler soil, and higher soil water content decreases diurnal differences between day-time and night-time temperatures (Al-Kayssi et al., 1990). Since soils managed under reduced tillage tend to have greater water holding capacity overall, reduced tillage maintains more even diurnal temperature, with lower temperatures than conventional tillage in the daytime, but higher temperatures at night (Johnson and Hoyt, 1999; TerAvest et al., 2015).

Reduced Tillage and Crop Residue

Reduced tillage leaves crop residue on the soil surface because of lack of soil inversion. Residue is the dead plant tissue left behind on the soil surface from harvested cash crops, terminated cover crops, and killed weeds. Surface residue can be beneficial by decreasing evaporation of soil water, reducing erosion from wind and water, and increasing water storage in reduced-till soils (Power et al., 1986; Laufer et al., 2016; Wilhelm et al., 1986). Residue in reduced-till systems increases soil organic matter as it slowly decomposes and leaches nutrients into the soil (Doran, 1980; Power et al., 1986; Sharifi et al., 2008). Surface residue intercepts rain drops, preventing surface sealing and erosion (Tebrügge and Düring, 1999). Sufficient residue can block light from emerging weeds.

Residue can also be problematic in farming systems by blocking light from emerging crop seeds and decreasing seed to soil contact of broadcast seed. Residue can get caught in machinery and interfere with the functionality of seeders, harvesters, and other farm equipment. Increased surface residue in a chisel plow system compared with moldboard plow system decreases establishment of maize and decreases precision of sowing (Raoufat and Mahmoodieh, 2005).

Reduced Tillage and Soil Nutrients

Plants need essential nutrients to function and grow. Adequate soil concentrations of plant-available nutrients is imperative for healthy crops. Nutrient availability in the soil depends on soil moisture, temperature, organic matter content, microbial activity, and pH. Certain nutrients become unavailable at high or low pH, and temperature dictates the activity of microbes, which convert organic matter into nutrients available to plants.

Tillage affects soil nutrients by influencing soil temperature, moisture, microbial activity, and organic matter content. Reduced tillage soils have higher organic matter than tilled soils due to the slow release of carbon from surface residue and the ability of soil organisms such as fungi to form undisturbed networks of hyphae. Reduced soil disturbance increases the biomass and metabolic activity of soil organisms, which contribute to increases in soil nitrogen mineralization and plant available nutrients. Soil carbon is maintained in reduced tillage soils by decreasing the amount of soil carbon lost to oxidation by soil inversion and heating. High soil organic matter content increases cation exchange capacity and plant available nutrients in the soil (Balesdent et al., 2000; Power et al. 1986; Ramos et al., 2018). Organic matter has a net negative charge due to the separation of organic acids into smaller groups, and attracts cations to the soil surface. Organic matter can have 4-50 times greater cation exchange capacity than clay (Fenton et al., 2008). Many important plant nutrients are cations, such as potassium, magnesium, and calcium, so high cation exchange capacity increases nutrient availability in the soil.

Reduced tillage soil has a lower pH than tilled soil (Mendoza, 2008; Wicks, 1988; Blevin, 1982). Tilled soil can have higher pH due to incorporation of added lime. Unmixed soil in reduced tillage systems can cause exchangeable bases to leach downward. Exchangeable base cations, especially calcium, leach more from no-till soils as compared with tilled soils, and surface pH (0-5 cm) decreases from alkaline to a pH between 5.2-5.8 after 18 years (Mendoza et al., 2008). Lower pH and lower temperatures associated with no-till may adversely affect nutrient mineralization and availability.

Both nutrient concentrations and organic matter in reduced-till soils are strongly influenced by stratification: the uneven distribution of nutrient concentrations over a given depth of soil. No-till managed soils have higher organic matter and nitrogen concentrations than conventionally tilled soils in the upper layers of soil, but equal or lower concentrations in deeper layers (Angers et al., 1997; Dick, 1983; Franzluebbers, 2002; de Oliveira Ferreira et al., 2013). When soil is taken from a 60 cm depth and mixed, there is no difference in carbon or nitrogen content between till and no-till (Angers et al., 1997). Soil carbon becomes stratified in no-till soils whereas it is uniformly distributed in tilled soils, with a ratio shallow:deep C concentration of 5.3 in no-till and 1.4 in conventional-till (Franzleubbers, 2002).

Managing Weeds in Reduced Till and Organic Systems

The National Organic Program (NOP) defines organic production as a system that "responds to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biological diversity" [§ 205.2]. There are organically certified, non-synthetic pesticides, but organically certified herbicides are virtually non-existent (U.S. Department of Agriculture, 2012), making organic weed management dependent on biological and mechanical approaches. Organic systems have higher weed diversity and density compared with conventional systems (Campiglia et al., 2017; Ryan et al., 2009). It is difficult to suppress weeds without chemical control, but it is more difficult to eliminate both chemical and mechanical weed-control methods from cropping systems.

Weed density and biomass are higher in reduced-till systems than conventional-till systems (Campiglia et al., 2017; Cavalaris and Gemtos, 2002; Nakamoto et al., 2006). Intensive tillage buries seeds and plants, cuts or uproots aboveground stems and seedlings, and destroys the roots of annual and perennial weeds. Indirectly, tillage can kill weeds by drying the soil or exhausting seed food reserves.

Tillage method can shift weed species populations. Perennial weeds are more prevalent in reduced-till systems than in conventional-till systems (Campiglia et al., 2017; Nakamoto et al., 2006; Schipanski et al., 2014; Tørresen et al., 2002). Perennial weed biomass in Norway is nearly 50% lower in deep-tilled soil (25 cm) compared with shallow-tilled soil (15 cm) in an organic cereal system (Brandsæter et al., 2011). Hemp dogbane (*Apocynum cannabinum*), field bindweed (*Convonvulus arvensis*), and dandelion (*Taraxacum officinale*) populations increase in long-term reduced-till and no-till systems in Iowa compared with conventional-till systems (Buhler et al., 1994). American germander (*Teucrium canadense*) populations, however, increase in a moldboard plow system compared with reduced-till. Tillage also increases the dispersal capabilities of Johnson grass rhizomes (Andújar et al., 2012).

Most perennial weeds reproduce by vegetative propagation, forming new plants from rhizomes, roots, stems, bulbs, corms, and stolons rather than by seed alone. Perennials have thick roots that store carbohydrate reserves throughout the growing season, enabling them to survive long periods of time in non-ideal circumstances, such as over winter, in disturbed soils, and in environments with low water and nutrient availability (Bhowmik, 1997). Inversion tillage can bury perennial weeds deeply enough to exhaust these reserves as the plant attempts to grow through deep soil to light. Other forms of intensive tillage, such as rototilling and discing, can kill perennials by continuously chopping vegetative propagules into smaller fragments, which take longer to sprout and have fewer carbohydrate reserves (Bhowmkik, 1997). In time, this may eradicate a perennial population, but if a perennial weed species is vigorous enough to emerge through deep soil or recover from being chopped into smaller fragments, tillage may encourage the spread of perennial weeds by spreading vegetative propagules through the soil (DiTomasso, 2017).

Many annual weeds are triggered to germinate by light exposure, soil aeration, and soil warming facilitated by tillage. Dormancy of buried weed seeds can be broken by tillage that brings seeds to the soil surface and exposes them to light. If tillage systems on a farm are continually switched (ie. no till, rotary harrow, rototill rotation), some weed species may be selected for by bringing up new seeds and allowing them to remain near the soil surface for a period of time (Nakamoto et al., 2006). This system is unlikely to select for specific traits in weed species.

The effect of tillage on weeds is species-specific, dependent upon the germination requirements, dispersal mechanisms, and resilience of individual species. Even within a species, individual response of weeds to tillage can vary, and other factors, such as crop rotations, soil amendments, mulching, temperature, rainfall, and seed predation can have stronger impacts on weed survival. Pigweed responds inconsistently to tillage treatments, correlating more highly with soil nitrogen (Nakamoto et al., 2006). Others find pigweed population density is highest in a conservation tillage system after a winter fallow compared with conventional tillage systems and cover crops, but is also strongly impacted by the prevalence of winter cover crop residue (Price et al., 2009).

Tillage impacts weed seed banks in soils and population dynamics of weeds. Weed seed banks are increased by dispersal of seeds and decreased by germination, decay, and predation (DiTomasso, 2017). Tillage influences the vertical distribution of seeds, which affects seed exposure to light, moisture, predators, and temperature fluctuation. Eighty-five percent of the weed seed bank is in the upper 5 cm of soil in reduced-till and only 28% in conventional-till in South Australia (Chauhan et al. 2006). Within that top 5 cm of soil, 56% of weed seeds are in the top 1 cm of no-till soil and only 5% are in the top 1 cm in reduced-till soil (Chauhan et al., 2006). Over 60% of weed seed is in the upper 5 cm of both no-till and reduced-till systems, but has an even distribution to 15 cm in a moldboard plow system (Clements et al., 1996).

Reduced-till systems can increase seed decay and predation. More seed predators - rodents, crickets, ants, beetles, and insect larvae - are present in the upper layers of the soil, and seed mortality is higher near the soil surface than buried deeply (Baraibar et al., 2017; Chauhan et al., 2006). Crop residue present on the soil surface in reduced-till systems can also inhibit the emergence of weed seedlings by blocking light (Chauhan et al., 2012).

Weed dynamics and tillage is a complicated interaction. Despite the potential for increased seed predation and decay in reduced tillage systems, reduced tillage creates higher weed pressure than conventional tillage and can be a risky practice to implement in high value crops, because yield loss has low economic thresholds for these crops. Residue management, crop rotation, cover cropping, and other cultural control methods of weed management can increase the efficacy of reduced tillage in organic systems.

Reduced Tillage and Beets

Table beets are a fresh market vegetable gaining in popularity among consumers and small-scale vegetable farmers. New York is the second highest producer of beets in the United States (U.S. Department of Agriculture, 2012). Beets are generally a direct-seeded crop, meaning farmers plant the seeds, or seed clusters, directly into the soil in the field, rather than transplanting seedlings. Difficulty direct seeding into crop residue in reduced-till systems can put stress on beet emergence and stands. Root crops are sensitive to soil conditions, which change under different tillage systems. The effect of tillage on table beets (*Beta vulgaris L.*) and beets in organic systems is poorly studied. However, studies in sugar beets provide some background for beet response to reduced tillage systems.

Inter-row loosening of the soil increases organic sugar beet yield compared with cutting, mulching, and thermal weed control in Lithuania. Conventional sugar beet yield is unaffected by tillage treatments of deep and shallow plowing, chiseling/discing, or no-till (Šarauskis et al., 2018).

Reduced tillage systems often have negative impacts on conventional sugar beet yield. Direct seeding into reduced-till soil decreases sugar beet yield compared with direct seeding into moldboard plowed soil (Koch et al., 2009). Sugar beet yield in Greece decreases by 1-47% with reduction in tillage (Cavalaris and Gemtos, 2002). In contrast, sugar beet yield across multiple European countries decreases in no-till, but yields in reduced-till are comparable to conventional-till (Van den Putte et al., 2010). Decreased yields are largely attributed to increased soil strength.

Tillage affects root crops, such as beets, by influencing secondary growth of the taproot. Soil compaction caused by tractor traffic increases soil strength, but as stated earlier, bulk density is generally higher in the top 10 cm of soil in no-till soils compared with tilled soils. High soil strength inhibits the growth of roots (Yapa et al., 1988). Soil compaction from tillage equipment traffic can reduce sugar beet taproot quality, yield, and leaf area by as much as 10% (Marinello et al., 2017). Sugar beet yield in Sweden shows a curvilinear relationship with soil compaction, with an optimal intermediate soil strength and sharply decreased yields at 90 degrees of compaction from high-compaction traffic (Arvidsson and Håkansson, 2014).

Part 2: Plastic in vegetable production systems

Plastic soil covers or films are a common practice in both organic and conventional vegetable production. Farmers use synthetic covers before seeding, such as solarization and tarping, or during the growing season, such as polyethylene film. For solarization, farmers use transparent plastic sheets applied to soils at times of bright sunlight and high atmospheric heat. These temporary soil covers raise surface soil temperature to extreme levels that may kill weed seeds, pathogens, and other pests. Farmers apply polyethylene film to planting beds, burying the edges of film with soil and leaving them in place throughout the growing season.

Clear Tarps for Solarization

Solarization film consists of transparent polyethylene, usually of 1-4 mil weight. Some farmers use greenhouse film or painter's plastic to solarize soils. Transparent plastic lies on the soil surface, secured by heavy objects or buried with soil, for a number of days or weeks in conditions of high sunlight and temperatures.

Soil solarization reduces weed density and biomass and increases yields in a variety of crops (Abu-Gharbieh et al., 1988; Candido et al., 2011; Egley, 1983;

Kanaan et al., 2018; Khan et al., 2012; Linke, 1994; Samtani et al., 2017). Solarization controls and suppresses most annual weed species, but effects are species specific (Khan et al., 2012; Linke, 1994). In southern Italy, solarization for two months controls almost all annual species, including purslane (*Portulaca oleracea*) and redroot pigweed (*Amaranthus retroflexus*), but few perennial species (Candido et al., 2011). In Pakistan, solarization of two weeks decreases weed biomass and density, but has little effect on some species, such as common lambsquarters (*Chenopodium album)*, and stimulates growth of other species, such as common vetch (*Vicia sativa)* (Khan et al., 2012). Solarization in Mississippi for one to four weeks significantly lowers emergence of annual weed seedlings, including horse purslane (*Trianthema portulacastrum*), prickly sida (*Sida spinosa*), and many grasses, and has significant impact on weeds in the process of germinating, but does not control purple nutsedge (*Cyperus rotundus*) (Egley, 1983).

Both black and transparent polyethylene control weeds after two and a half months of solarization in Israel. Transparent polyethylene is more effective than black, with 3.4% and 15% reemergence of weeds in transparent and black treatments respectively, in comparison to bare ground (Horowitz et al., 1983). In contrast, black polyethylene tarps in Jordan are as effective as transparent polyethylene at improving crop yields and comparable at reducing fungi and nematode populations (Abu-Gharbieh et al., 1988).

Clear plastic heats the soil by transmitting shortwave radiation from the sun, which the soil absorbs (Ham et al.,1993; Ham and Kluitenberg, 1994). Shortwave radiation contains a high amount of energy, and the soil heats rapidly when this radiation is absorbed. To kill weeds and weed seeds, solarization must heat the soil to 40-65°C (Abu-Gharbieh et al., 1988; Egley, 1983; Öz, 2018). Solarization is likely less effective in the Northeast, since summer temperatures may not get high enough for long enough to heat the soil to 40°C or more. Since highest soil temperatures can be achieved with solarization in the summer, this would restrict or eliminate cash crop production in Northeastern fields.

Table 3. Summary of solarization data detailing treatment duration, temperatures reached, and weed control efficacy.

Author	Location	Duration	Temperature	Weed Control
Abu-Garbieh, Saleh, and Abu-Blan, 1988	Jordan	10 weeks	42-50°C average	NA; effectively controlled many species of fungi and nematodes
Candido et al 2011	Italy	8 weeks	Most treatments reached 45-50°C, highest 60°C, all reached 40-45°C	Lowered weed biomass; controlled annual weeds and some perennials (Canada thistle)
Egley, 1983	Mississippi (USA)	1-4 weeks	38-65°C range, above 55°C 10-21 days and above 60°C 5-21 days	Decreased viable seed and emergence; controlled all weed species except purple nutsedge
Khan et al, 2012	Pakistan	2-10 weeks	50°C avg, over 45°C majority of time	Lowered weed biomass and controlled many annual weeds and Canada thistle; did not control lambsquarters or vetch
Linke, 1994	Syria	3-7 weeks	57°C max temperature, average 6.9-8.5°C higher under plastic than control	Reduced annual weeds; did not control perennials
Öz, 2018	Turkey	8 weeks	39-41°C average	Lowered weed biomass
Samtani et al, 2017	Virginia (USA)	4-6 weeks	Periods above 40°C; average 4-5°C hotter under plastic than control	Significantly lower weed density with 6-week treatment

Plastic Film

Farmers in vegetable production systems have a long history of using polyethylene film. Plastic films are thin (1 -2 mil) sheets of polyethylene that come in a variety of colors. Farmers use specialized equipment to stretch plastic film over formed beds and bury the edges with soil, then cut or burn holes in the film to transplant or even direct seed crops into the bed. Hoses or tape underneath plastic mulch facilitates drip irrigation.

Dark or black plastic films prevent light penetration to the soil surface that many weed seeds need to germinate and grow. Black plastic absorbs almost all shortwave radiation from the sun (Ham et al., 1993; Ham and Kluitenberg, 1994). Rather than heating the soil by shortwave transmittance, like clear plastic, black plastic heats the soil by thermal conductivity. Black plastic absorbs the energy of shortwave radiation and transfers collected heat to the soil by directy contact. The air layer between plastic and the soil makes a significant difference in soil warming, with higher heat transmittance following higher plastic-soil interface (Ham and Kluitenberg, 1994; Liakatas et al., 1985). Black plastic also traps longwave radiation emitting from the soil. This lower energy radiation still has an effect on soil temperature. Clear plastic allows up to 80% of longwave radiation to escape from the soil, while black plastic only allows 9-67% to escape, more effectively trapping heat in the soil (Ham et al., 1993, Ham and Kluitenberg 1994). Temperatures under plastic film average 3-6°C higher than bare soil temperatures (Canul-Tun et al., 2017; Filipovic et al., 2016; Ramakrishna et al., 2006).

Plastic films slow the loss of soil moisture by preventing evaporation, slow nutrient loss by preventing leaching, and increase surface temperatures by trapping the sun's energy (Fritz, 2012, Gu et al., 2018; Kasirajan and Ngouajio, 2012; Fan et al., 2017; Zhang et al., 2017). Plastic films of any type increase crop yield of a variety of crops (Canul-Tun et al., 2017; Fan et al., 2017; Filipovic et al., 2016; Gu et al., 2018; Icard et al., 2010; Torres-Olivar et al., 2016; Zhang et al., 2017).

Plastic films are more effective than other types of mulch in both weed suppression (by density and by species) and insulation (Icard et al., 2010; Ramakrishna et al., 2006). Polyethylene film offers better insulation and produces significantly higher crop yield of ground nut than other mulches at 94.5% higher yield than unmulched, 46.8% higher yield than chemically mulched, and 25.5% higher yield than straw mulch (Ramakrishna et al., 2006).

Black film is more effective at suppressing weeds than clear film, as clear film promotes weed growth at moderate temperatures (Fritz, 2012). In many cases, black plastic film significantly increases crop yield compared with both bare ground and colored film, such as white or silver (Canul-Tun et al., 2017; Filipovic et al., 2016; Fritz, 2012). In Mexico, red and white film can support higher yields of cucumber than black due to the reflective property of the plastic onto the leaves of the crop during the growing season (Torres-Olivar et al., 2016). White-on-black film in Texas blackberry production causes the highest increase in crop yield compared to three different types of landscape fabric and bare ground due to its reflective properties, resulting in lower and more stable soil temperatures (Makus, 2011). In Georgia, however, bell pepper yield decreases in black plastic mulch systems compared with silver plastic mulch systems due to increased heat stress in the root zone with black plastic (Díaz-Pérez, 2010). Black plastic may not be the best color choice if farmers want the soil cooled, if outside temperatures are high enough that clear plastic will heat the soil enough to kill weeds, or if reflective qualities to deter insect pests or increase light absorption of leaves is a higher priority than weed suppression.

Landscape Fabric

Landscape fabric is a permeable material woven of polypropylene or polyester. Like plastic film, farmers use landscape fabric for weed control by leaving it on the soil surface throughout the season and planting crops into holes in the fabric. Unlike plastic film, clear tarps, or silage tarps, landscape fabric allows water and air to penetrate to the soil. Impermeable plastic can have negative effects if used long-term with perennial crops, such as trees. Impermeable plastic can limit water availability and soil oxygen levels, restricting root growth (Appleton et al., 1990; Whitcomb, 1980). Landscape fabric suppresses annual weed species in annual crop systems compared to bare soil (Billeaud and Zajicek, 1989; Derr and Appleton, 1989; Marble et al., 2015; Skroch et al., 1992). Considering yield and labor costs, landscape fabric is a good alternative to polyethylene plastic mulch long-term in vegetable production due to its greater durability (Feldman et al., 2009).

Landscape fabric is not effective at killing perennial weeds or as a long-term control in perennial cropping systems, as weeds can emerge under the fabric, or seeds deposited on top of the fabric can germinate and penetrate the mulch with their roots (Derr and Appleton, 1989; Marble, 2015; Skroch et al., 1992). In perennial or landscape systems, farmers and workers place organic mulches on top of landscape fabric. This may not be applicable in annual vegetable systems (Appleton et al., 1990; Billeaud and Zajicek, 1989; Derr and Appleton, 1989; Skroch et al., 1992).

Landscape fabric increases and stabilizes soil surface temperatures, though temperature increases are less than that of black plastic (Appleton et al., 1990). Nitrogen content increases under landscape fabric compared to bare soil, and use of any soil cover lowers soil pH (Billeaud and Zajicek, 1989). Landscape fabric also increases the presence of voles. Although voles potentially increase weed seed and seedling predation, they can cause root and plant damage to crops (Appleton et al., 1990).

Tarps

A tarp as defined by this research is a moveable sheet of 6 mil black polyethylene that is impermeable to water. Manufacturers and farm suppliers sell tarps that are 100 ft long and range in width from 24-50 ft - long enough to cover multiple beds in a field. Farmers can cut tarps to any size and roll or fold them for storage. If farmers protect tarps from sunlight, rodents, and excessive moisture during storage and are careful not to tear tarps while moving them, tarps can last many years.

Farmers secure tarps to the soil surface using similar methods as floating row covers, such as sandbags, rocks, or pegs. Tarps can lay on fully prepared soil - lightly tilled, amendments added, or residue incorporated - or directly over a mowed cover crop or weeds. Farmers can leave tarps in place for any number of weeks or months. Tarp application is not dependent on weather or soil conditions. Using tarps conserves fuel use and labor hours by reducing tillage and can decrease soil compaction if farmers need less heavy machinery for tillage.

Black plastic controls weeds in non-agricultural settings as well. Land managers use landfill-grade tarps to suppress invasive weeds in natural ecosystems. After two growing seasons, tarps control annual weeds in California wetlands, but do not suppress perennial pepperweed (*Lepidium latifolium*) without a mow-till-tarp combined approach (Hutchinson and Viers, 2011).

Using black tarps to control weeds and residue is a wide-spread practice on small-farms in the northeast. Jean Martin Fortier popularized the use of 'silage tarps' for weed occultation in his book 'The Market Gardener' in 2014 (Fortier, 2014). This book inspired small-scale organic farmers to use tarps, often in conjunction with a bed former and thick layer of compost, to kill weeds and preserve prepared planting beds. Some farmers apply tarps in late fall and leave them in place overwinter; others put tarps down just a few weeks before planting in spring or summer. Some farmers till or apply compost prior to laying tarps, and some lay tarps directly over living cover crops or weeds (Baruc, Martin, Munzer, Saeli, personal communication).

In Quebec, tarps kill emerged weeds and degrade crop debris within three weeks (Fortier, 2014). Even within two weeks, soil under black tarps is free of weeds (Birthisel, 2018; Lounsbury et al., 2018). Tarps significantly decrease weed density compared with uncovered soil 14 days post tarp removal (Birthisel, 2018). Even by the end of the cropping season, tarps may decrease weed biomass compared with uncovered soil (Lounsbury et al., 2018).

Tarps kill a winter-rye/hairy vetch cover crop within two weeks and degrade residue by over 1100 kg/ha compared with no-tarp treatments. They decrease soil temperature and have less fluctuation in soil moisture compared with uncovered soil (Lounsbury et al., 2018). Both black and clear tarps of two or more weeks increase cabbage yield by 58% compared with no-tarp treatments in New Hampshire (Lounsbury et al., 2018).

There are drawbacks to using black plastic tarps. Tarps consume beds for weeks or months, interfering with small-scale intensive production plans, delaying spring planting and increasing turnover time from one crop to the next. Tarps are large and heavy and can be difficult to lay, store, and manage. Some farmers cut tarps into smaller pieces to ease handling, but this takes time.

Water can pond on top of tarps, increasing their weight and causing issues with runoff management. Farmers should position tarps so that water can run off edges into a drainage ditch away from crop rows. Some farmers cut small holes in tarps to allow for better drainage.

Tarps are a relatively cheap option for farmers on a small scale, costing between $100-290 for a 30 m tarp of various widths (7-15 m). On a larger scale, however, tarps can become very expensive and may not make economic sense.

Despite the limitations of tarps on the farm and lack of evidence-based research on the mechanisms of how they impact weeds and the soil, a large number of farmers across the Northeast use tarps on their farms. This research seeks to assess the efficacy of using tarps in organic, reduced-till vegetable systems to suppress weeds, decompose crop residue, and reduce tillage while increasing crop yield. It analyzes how tarps impact the soil environment, and provides information on how farmers can best use tarps in their vegetable systems to promote soil health and increase farm productivity.

Works Cited

Abu-Gharbieh, W.I., Saleh, H., and H. Abu-Blan. 1988. Use of black plastic for soil solarization and post-plant mulching. Plant Protection Dept., Faculty of Ag., Univ. of Jordan, Amman, Jordan.

Al-Kayssi, A.W., A.A. Al-Karaghouli, A.M. Hasson, and S.A. Beker. 1990. Influence of soil moisture content on soil temperature and heat storage under greenhouse conditions. J. Ag. Eng. Res. 45:241-252.

Allmaras, R.R., T.H. Dao, C.L. Jr. Douglas, and H.H. Schomberg. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. J. Soil Water Conservation 55(3):365–73.

American Society of Agricultural Engineers. 2005. Terminology and Definitions for Soil Tillage and Soil-Tool Relationships." EP291.3. February, 2005.

Andújar, D., J. Barroso, C. Fernández-Quintanilla, and J. Dorado. 2012. Spatial and temporal dynamics of *Sorghum halepense* patches in maize crops. Weed Res. 52:411-420.

Angers, D.A., M.A. Bolinder, M.R. Carter, E.G. Gregorich, C.F. Drury, B.C. Liang, and R.P. Voroney. 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. Soil Tillage Res. 41:191-201.

Appleton, B.L., J.F. Derr, and B.B. Ross. 1990. The effect of various landscape weed control measures on soil moisture and temperature, and tree root growth. J. Arboriculture 16(10):264-268.

Arshad, M.A., A.J. Franzluebbers, and R.H. Azooz. 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil Tillage Res. 53:41-47.

Arvidsson, J. and I. Håkansson. 2014. Response of different crops to soil compaction-short-term effects in swedish field experiments. Soil Tillage Res. 138:56-63.

Balesdent, J., M. Balabane, and C. Chenu. 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil Tillage Res. 53(3/4):215–30.

Baraibar, B., C. Canadell, J. Torra, A. Royo-Esnal, and J. Recasens. 2017. Weed seed fate during summer fallow: The importance of seed predation and seed burial. Weed Sci. 65:515-524.

Beare, M.H., S. Hu, D.C. Coleman, and P.F. Hendrix. 1997. Influences of mycelial fungi on soil aggregation and organic matter storage in conventional and no-tillage soils. Appl. Soil Ecol. 5(3):211–19.

Bhowmik, P.C. 1997. Weed biology: Importance to weed management. Weed Sci. 45(3):349–56.

Billeaud, L.A. and J.M. Zajicek. 1989. Influence of mulches on weed control, soil pH, soil nitrogen content, and growth of *Ligustrum japonicum*. J. Env. Hort. 7(4):155-157.

Birthisel, S.K. 2018. Multi-tactic ecological weed management in a changing climate. Univ. of Maine, Orono, PhD Diss. 2928.

Blevins, R.L., G.W. Thomas, M.S. Smith, W.W. Frye, and P.L. Cornelius. 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. Soil Tillage Res. 3:135-146.

Brandsæter, L.O., A.K. Bakken, K.M., H. Riley, R. Eltun, and H. Fykse. 2011. Effects of tractor weight, wheel placement and depth of ploughing on the infestation of perennial weeds in organically farmed cereals. European J. of Agron. 34:239-246.

Buhler, D.D., D.E. Stoltenberg, and R.L. Becker. 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. Weed Sci. 42:205-209.

Campiglia, E., E. Radicetti, and R. Mancinelli. 2018. Floristic composition and species diversity of weed community after 10 years of different cropping systems and soil tillage in a Mediterranean environment. Weed Res. 58:273-283.

Candido, V., D. Castronuovo, V. Miccolis, and T. D'Addabbo. 2011. Weed control and yield response of soil solarization with different plastic films in lettuce. Scientia Horticulturae 130:491-497.

Canul-Tun, C.E., L. Ibarra-Jimenez, L.A. Valdez-Aguilar, A.J. Lozano-del Rio, A. Cardenas-Flores, A. Zermeno-Gonzalez, C.J. Lozano-Cavazos, J.H. Valenzuela-Soto, and V. Torres-Olivar. 2017. Influence of colored plastic mulch on soil temperature, growth, nutrimental status, and yield of bell pepper under shade house conditions. J. Plant Nutr. 40(8): 1083-1090.

Cavalaris, C.K. and T.A. Gemtos. 2002. Evaluation of four conservation tillage methods in the sugar beet crop. CIGR J. Sci. Res. Dev. 4.

Chauhan, B.S., G.S. Gill, and C. Preston. 2006. Tillage system effects on weed ecology, herbicide activity and persistence: A review. Australian J. Expt. Ag. 46:1557-1570.

Chauhan, B.S., R.G. Singh, and G. Mahajan. 2012. Ecology and management of weeds under conservation agriculture: A review. Crop Protection 38:57-65.

Clements, D.R., D.L. Benott, S.D. Murphy, D.L. Benoit, and C.J. Swanton. 1996. Tillage effects on weed seed return and seedbank composition. Weed Sci. 44(2):314-322.

Conservation Technology Information Center. 2004. National Crop Residue Management Survey: Tillage Type Definitions.

Crittenden, S.J. and R.G.M. de Goede. 2016. Integrating soil physical and biological properties in contrasting tillage systems in organic and conventional farming. European J. Soil Biol. 77: 26-33.

Derr, J.F. and B.L. Appleton. 1989. Weed control with landscape fabrics. J. Env. Hort. 7(4):129-133.

Díaz-Pérez, J.C.. 2010. Bell pepper (*Capsicum annum* L.) grown on plastic film mulches: Effects on crop microenvironment, physiological attributes, and fruit yield. Hort. Sci. 45(8):1196-1204.

Dick, W. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. Soil Sci. Soc. of Amer. J. 47.

DiTommaso, T. 2017. Weed Biology and Management. Cornell University, Ithaca, New York. Lecture.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. of Amer. J. 44:765–71.

Dörner, J. and R. Horn. 2009. Direction-dependent behaviour of hydraulic and mechanical properties in structured soils under conventional and conservation tillage. Soil Tillage Res. 102:225-232.

Drakopoulos, D., J.M.S. Scholberg, and E.A. Lantinga. 2018. Influence of reduced tillage and fertilisation regime on soil quality indicators in an organic potato production system. Biol. Ag. Hort. 34 (2):132–40.

Egley, G.H. 1983. Weed seed and seedling reductions by soil solarization with transparent polyethylene." Weed Sci. 31.

Fan, Y., L. Tong, R. Ding, S. Kang, S. Li, T. Du, and X. Hao. 2017. Plastic mulch decreases available energy and evapotranspiration and improves yield and water use efficiency in an irrigated maize cropland. Ag. Water Mgt. 179:122–31.

Feldman, R.S., C.E. Holmes, and T.A. Blomgren. 2000. Use of fabric and compost mulches for vegetable production in a low tillage, permanent bed system: Effects on crop yield and labor. Amer. J. Alternative Ag. 15(4):146-153.

Fenton, M., C. Albers, and Q. Ketterings. 2008. Soil organic matter. Cornell Coop. Ext. Ag. Fact Sheet 41.

Filipovic, V., D. Romic, M. Romic, J. Borosic, L. Filipovic, F.J.K. Mallmann, and D.A. Robinson. 2016. Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: Experimental results and a modeling study. Ag. Water Mgt. 176:100–110.

Food and Agriculture Organization of the United Nations. 2005. The importance of soil organic matter: Chapter 5. <http://www.fao.org/docrep/009/a0100e/a0100e08.htm>

Fortier, J.M. 2014. The Market Gardener: A Successful Grower's Handbook for Small-scale Organic Farming. New Society, B.C., Can.

Fox, C.A., J.J. Miller, M. Joschko, C.F. Drury, and W.D. Reynolds. 2017. Earthworm population dynamics as a consequence of long-term and recently imposed tillage in a clay loam soil. Can. J. Soil Sc. 97(4):561–79.

Franzluebbers, A.J. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Tillage Res. 66:197-205.

Fritz, V.A. 2012. Plastic mulches: Benefits, types, and sources. Minnesota High Tunnel Production Manual for Commercial Growers. 2nd ed. Univ. Minn.

Gardiner, D.T. and R.W. Miller. 2008. p. 75, 82. In: Soils in Our Environment. 11th ed. Pearson, Columbus, Ohio.

Grubiner, V.P.. 1999. p. 88-93. In: Sustainable Vegetable Production from Start-Up to Market. Plant and Life Sciences Publishing, Ithaca, N.Y.

Gu, Y-J., C-L. Han, J-W. Fan, X-P. Shi, M. Kong, X-Y. Shi, K.H.M. Siddique, Y-Y. Zhao, and F-M. Li. 2018. Alfalfa forage yield, soil water and P availability in response to plastic film mulch and P fertilization in a semiarid environment. Field Crops Res. 215:94–103.

Gupta, V.V.S.R. and J.J. Germida. 1988. Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. *Soil Biol. and Biochem.* 20(6):777–86.

Ham, J.M., G.J. Kluitenberg, and W.J. Lamont. 2019. Optical properties of plastic mulches affect the field temperature regime." J. Amer. Soc. Hort. Sci. 118(2):188–93.

Ham, J.M. and G.J Kluitenberg. 1994. Modeling the effect of mulch optical properties and mulch-soil contact resistance on soil heating under plastic mulch culture. J. Agr. Forest Meteorol. 71:403-424.

Havlin, J.L., S.L. Tisdale, W.L. Nelson, and J.D. Beaton. 2016. p. 472. In: Soil Fertility and Fertilizers: An Introduction to Nutrient Management. 8th ed. Pearson, India.

Hill, R L. 1990. Long-term conventional and no-tillage effects on selected soil physical properties. Soil Sci. Soc. Amer. J. 54:161-166.

Hill, R.L., R. Horton, and R.M. Cruse. 1985. Tillage effects on soil water retention and pore size distribution of two mollisols. Soil Sci. Soc. Amer. J. 49:1264-1270.

Horowitz, M., Y. Regev, G. Herzlinger, and G. Herzlinger. 1983. Solarization for Weed Control. Weed Sci. 31(2):170-179.

Hudson, B.D. 1994. Soil organic matter and available water capacity. J. Soil Water Conservation 49(2):189–94.

Hungria, M., J.C. Franchini, O. Brandão-Junior, G. Kaschuk, and R.A. Souza. 2009. Soil microbial activity and crop sustainability in a long-term experiment with three soil-tillage and two crop-rotation systems. Appl. Soil Ecol. 42(3):288–96.

Hutchinson, R.A. and J.H. Viers. 2011. Tarping as an alternative for perennial pepperweed (*Lepidium latifolium*) control. Invasive Plant Sci. Mgt. 4(1):66–72.

Johnson, A.M. and G.D. Hoyt. 1999. Changes to the soil environment under conservation tillage. HortTechnology 9(3):380–93.

Johnson, M.D. and B. Lowery. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Soil Sci. Soc. Amer. J. 49:1547–52.

Jokela, D. and A. Nair. 2016. effects of reduced tillage and fertilizer application method on plant growth, yield, and soil health in organic bell pepper production. Soil Tillage Res. 163:243-254.

Kanaan, H., S. Frenk, M. Raviv, S. Medina, and D. Minz. 2018. Long and short term effects of solarization on soil microbiome and agricultural production. Appl. Soil Ecol. 124:54-61.

Kandeler, E. and E. Murer. 1993. Aggregate stability and soil microbial processes in a soil with different cultivation. Geoderma 56:503-513.

Kasirajan, S. and M. Ngouajio. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agron. for Sustainable Dev. 32:501-529.

Khan, M.A., R. Khan, H. Khan, H.U. Shah, K.B. Marwat, A. Amin, and A. Nawaz. 2012. Soil solarization: An organic weed-management approach in cauliflower. Commun. Soil Sci. Plant Analysis 43(13):1847–60.

Koch, H-J., B. Märländer, A. Büchse, and J. Dieckmann. 2009. Yield decrease in sugar beet caused by reduced tillage and direct drilling. European J. Agron. 30(2):101–9.

Laufer, D., B. Loibl, B. Märländer, and H-J. Koch. 2016. Soil erosion and surface runoff under strip tillage for sugar beet (*Beta vulgaris L.)* in central Europe." Soil Tillage Res. 162:1-7.

Liakatas, A., J.A. Clark, and J.L. Monteith. 1986. Measurements of the heat balance under plastic mulches part I: Radiation balance and soil heat flux. Agr. Forest Meteorol. 36:227-239.

Linke, K.H. 1994. Effects of Soil Solarization on Arable Weeds under Mediterranean Conditions: Control, Lack of Response or Stimulation. Crop Protection 13(2):115-120.

Lounsbury, N.P., N.D. Warren, S.D. Wolfe, and R.G. Smith. 2018. Investigating tarps to facilitate organic no-till cabbage production with high-residue cover crops." Renewable Ag. Food Systems. p. 1–7.

Makus, D.J. 2011. Use of synthetic ground covers to control weeds in blackberries. Intl. J. Fruit Sci. 11(3):286-298.

Marble, S.C., A.K. Koeser, and G. Hasing. 2015. A review of weed control practices in landscape planting beds: Part I - Nonchemical weed control methods. HortScience 50(6):851–56.

Marinello, F., A. Pezzuolo, D. Cillis, A. Chiumenti, and L. Sartori. 2017. Traffic effects on soil compaction and sugar beet (*Beta vulgaris L.*) taproot quality parameters. Spanish J. Ag. Res. 15(1).

Martínez, I., A. Chervet, P. Weisskopf, W.G. Sturny, J. Rek, and T. Keller. 2016. Two decades of no-till in the oberacker long-term field experiment: Part II - Soil porosity and gas transport parameters." Soil Tillage Res. 163:130-140.

Mendoza, R.B., T.G. Franti, J.W. Doran, T.O. Powers, and C.W. Zanner. 2008. Tillage effects on soil quality indicators and nematode abundance in loessial soil under long-term no-till production. Commun. Soil Sci. Plant Analysis 39:2169-2190.

Nakamoto, T., J. Yamagishi, and F. Miura. 2006. Effect of reduced tillage on weeds and soil organisms in winter wheat and summer maize cropping on humic andosols in central Japan. Soil and Tillage Res. 85(1-2):94–106.

Oliveira Ferreira, A. de, T.J.C. Amado, R. da Silveira Nicoloso, J.C. de Moraes Sá, J.E. Fiorin, D.S.S. Hansel, and D. Menefee. 2013. Soil Carbon Stratification Affected by Long-Term Tillage and Cropping Systems in Southern Brazil. Soil Tillage Res. 133:65-74.

Öz, Hasan. 2018. A new approach to soil solarization: Addition of biochar to the effect of soil temperature and quality and yield parameters of lettuce (*Lactuca sativa L. Duna*). Scientia Horticulturae 228:153–61.

Power, J.F., W.W. Wilhelm, and J.W. Doran. 1986. Crop residue effects on soil environment and dryland maize and soya bean production. Soil Tillage Res. 8:101–11.

Van den Putte, A., G. Govers, J. Diels, K. Gillijns, and M. Demuzere. 2010. Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. European J. Agron. 33:231-241.

Ramakrishna, A., H.M. Tam, S.P. Wani, and T.D. Long. 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam.” Field Crops Res. 95:115-125.

Ramos, F.T., E.F.G. de Carvalho Dores, O.L. dos Santos Weber, D.C. Beber, J.H. Campelo, and J.C.de Souza Maia. 2018. Soil organic matter doubles the cation exchange capacity of tropical soil under no-till farming in Brazil. J. Sci. Food and Ag. 98:3595-3602.

Raoufat, M. H. and R.A. Mahmoodieh. 2005. Stand establishment responses of maize to seedbed residue, seed drill coulters and primary tillage systems.” Biosystems Eng. 90(3):261–69.

Reicosky, D.C. 1997. Tillage-induced CO2 emission from soil. Nutrient Cycling Agroecosystems. 49: 273-285.

Roberson, E.B., M.K. Firestone, and S. Sarig. 1991. Cover crop management of polysaccharide-mediated aggregation in an orchard soil. Soil Sci. Soc. Amer. J. 55(3):734–38.

Ryan, M.R., R.G. Smith, D.A. Mortensen, J.R. Teasdale, W.S. Curran, R. Seidel, and D.L. Shumway. 2009. Weed-crop competition relationships differ between organic and conventional cropping systems. Weed Res. 49:572-580.

Samtani, J.B., J. Derr, M.A. Conway, and R.D. Flanagan III. 2017. Evaluating soil solarization for weed control and strawberry (*Fragaria xananassa*) yield in annual plasticulture production. Weed Tech. 31:455-463.

Šarauskis, E., K. Romaneckas, F. Kumhála, and Z. Kriaučiūnienė. 2018. Energy use and carbon emission of conventional and organic sugar beet farming. J. Cleaner Production 201:428-438.

Schipanski, M.E., R.G. Smith, T.L.P. Gareau, R. Jabbour, D.B. Lewis, M.E. Barbercheck, D.A. Mortensen, and J.P. Kaye. 2014. multivariate relationships influencing crop yields during the transition to organic management. Ag. Ecosystems Environ. 189:119-126.

Schlüter, S., C. Großmann, J. Diel, G.M. Wu, S. Tischer, A. Deubel, and J. Rücknagel. 2018. Long-term effects of conventional and reduced tillage on soil structure, soil ecological and soil hydraulic properties. Geoderma 332:10-19.

Sharifi, M., C.F. Drury, B.G. McConkey, N. Ziadi, S. Bittman, B.J. Zebarth, D.L. Burton, and C.A. Grant. 2008. Response of potentially mineralizable soil nitrogen and indices of nitrogen availability to tillage system. Soil Sci. Soc. Amer. J. 72(4):1124–31.

Silva-Olaya, A.M., C.E.P. Cerri, N. La Scala, Jr, C.T.S Dias, and C.C. Cerri. 2013. carbon dioxide emissions under different soil tillage systems in mechanically harvested sugarcane. Environ. Res. Letters 8.

Singh, A., V.K. Phogat, R. Dahiya, and S.D. Batra. 2014. Impact of long-term zero till wheat on soil physical properties and wheat productivity under rice-wheat cropping system. Soil Tillage Res. 140:98-105.

Skroch, W.A., M.A. Powelv, T.E. Bilderback, and P.H. Henry. 1992. Mulches: Durability, aesthetic value, weed control, and temperature. J. Environ. Hort. 10(1):43-45.

Tebrügge, F. and R.-A. Düring. 1999. Reducing tillage intensity: A review of results from a long-term study in Germany. Soil Tillage Res. 53:15–28.

TerAvest, D., L. Carpenter-Boggs, C. Thierfelder, and J.P. Reganold. 2015. Crop production and soil water management in conservation agriculture, no-till, and conventional tillage systems in Malawi. Ag. Ecosystems Environ. 212:285-296.

Tollner, E.W., W.L. Hargrove, and G.W. Langdale. 1984. Influence of conventional and netill practices on soil physical properties in the southern piedmont. Soil Water Conservation Soc. 39(1):73-76.

Torres-Olivar, V., A. Cardenas-Flores, H. Lira-Saldivar, L.A. Valdez-Aguilar, L. Ibarra-Jimenez, and M. Hernandez-Suarez. 2016. Effect of colored plastic mulch on growth, yield and nutrient status in cucumber under shade house and open field conditions." J. Plant Nutr. 39(14):2144–52.

Tørresen, K. Semb, R. Skuterud, H.J. Tandsæther, and M.B. Hagemo. 2003. Long-term experiments with reduced tillage in spring cereals: Effects on weed flora, weed seedbank and grain yield. Crop Protection 22:185-200.

Trewavas, A. 2004. A critical assessment of organic farming-and-food assertions with particular respect to the UK and the potential environmental benefits of no-till agriculture. Crop Protection 23:757-781.

U.S. Department of Agriculture. 2012. Census of Agriculture for 2012. U.S. Dept. Agr., Washington, D.C.

U.S. Department of Agriculture. 2012. Guide for Organic Crop Producers. U.S. Dept. Agr., Washington, D.C.

U.S. Department of Agriculture Natural Resources Conservation Service. 1996. Soil Quality Indicators: Aggregate Stability. <https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052820.pdf>

U.S. Department of Agriculture Natural Resources Conservation Service. 2008. Soil Quality Indicators: Bulk Density. <https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053256.pdf>

Voorhees, W.B. and M.J. Lindstrom. 1984. Long-term effects of tillage method on soil tilth independent of wheel traffic compaction. Soil Sci. Soc. Amer. J. 48:152-156.

Wang, J., H. Zhang, X. Li, Z. Su, X. Li, and M. Xu. 2014. Effects of tillage and residue incorporation on composition and abundance of microbial communities of a fluvo-aquic soil. European J. Soil Biol. 65:70–78.

Whitcomb, C.E. 1980. Effects of black plastic and mulches on growth and survival of landscape plants. Okla. Ag. Expt. Sta. J. Series 3628 6(1).

Wilhelm, W., J.W. Doran, and J.F. Power. 1986. Corn and soybean yield response to crop residue management under no-tillage production systems. Agron. J. 78:184-189.

Yapa, L.G.G., D.D. Fritton, and S.T. Willatt. 1988. Effect of soil strength on root growth under different water conditions. Plant Soil 109:9-16.

Zhang, Y-L., C.C. Shock, F-X. Wang, J-T. Qin, K-J. Yang, S-Z. Kang, and S-E. Li. 2017. Influence of Different Plastic Film Mulches and Wetted Soil Percentages on Potato Grown under Drip Irrigation. Ag. Water Mgt. 180:160–71.

Chapter 2: Black plastic tarp impact on soil measures, weed seeds, and crop residue

Introduction

Tarping has emerged as a practice used by small-scale organic farmers in the Northeastern United States to reduce weeds or hold prepared beds prior to planting. Tarps are reusable sheets of 0.15 mm opaque polyethylene impermeable to water and sized to cover multiple crop rows at a time. Farmers secure tarps to the soil surface for weeks or months prior to cash crop planting to provide benefits similar to tillage, such as early-season weed suppression and crop residue degradation.

Residue from past crops can cause problems in farming systems by interfering with the functionality of farm equipment and shading emerging crop seeds. Despite the prevalence of tarps on small-scale farms, there is little research analyzing how tarps affect residue degradation and the soil environment. In New Hampshire, both clear and black tarps kill a winter rye/hairy vetch cover crop within two weeks, and black tarps reduce crop residue more than 1100 $kg \cdot ha^{-1}$ compared with clear tarp and no-tarp treatments (Lounsbury et al., 2018). Farmers who use tarps report increased degradation of crop residue.

Plastic soil covers or films are a common practice in vegetable systems. Farmers use clear plastic sheets on the soil in bright sunlight and high heat to kill weed seeds and pathogens by solarization. Solarization suppresses most annual weed species and increases crop yield (Candido et al., 2011; Egley, 1983; Kanaan et al., 2018; Khan et al., 2012; Linke, 1994; Samtani et al., 2017). Plastic must heat the soil to 40-65°C to kill weed seeds and emerged weeds (Abu et al., 1988; Egley, 1983; Öz, 2018), making solarization unpredictable in the Northeast where summer temperatures are not always high enough to heat the soil above 40°C for extended periods of time or in the Spring.

Vegetable farmers commonly use polyethylene mulch films - thin plastic sheets that stretch to cover formed beds, remaining on the soil surface beneath crops during the growing season. Mulch films are opaque, blocking sunlight and heating the surface of the soil 3-6°C compared with uncovered soil (Canul-Tun et al., 2017; Filipovic et al., 2016; Ramakrishna et al., 2006; Yu et al., 2018). In the moderate temperatures associated with plastic mulch systems, black film suppresses weeds more efficiently that clear film, which can promote weed growth when temperatures are not hot enough to kill (Fritz, 2012). Black tarps used from July-September in Maine increase average soil temperatures 1-6°C compared with bare ground, though they do not heat the soil as much as clear plastic (Birthisel, 2018). In contrast, black tarps over a roller-crimped crover crop in June lower the average soil temperature compared with clear tarp or no tarp treatments (Lounsbury et al., 2018).

Soil moisture remains steady under black tarps compared with uncovered soil moisture, which fluctuates based upon rainfall events, and clear plastic, which decreases soil moisture (Lounsbury et al., 2018). Mulch films reduce soil moisture loss by preventing evaporation, and reduce nutrient leaching from rainfall (Fritz, 2012, Gu et al., 2018; Kasirajan and Ngouajio; Fan et al., 2017; Zhang et al., 2017).

Tarps significantly reduce weed density at the time of removal (Birthisel, 2018; Lounsbury et al., 2018), but the mechanisms behind tarp-weed seed interaction are unclear. Farmers observe thread-stage weed seedlings under tarps, indicating fatal germination of weeds which mimics a stale seedbed technique for annual weeds.

To better understand mechanisms of tarp impacts on soil, this research explored the effects of black tarps on the soil environment, including soil temperature, soil moisture, and nitrogen concentrations, and on the weed seed bank and surface crop residue prior to planting. Tarp impacts were studied in three locations and with two target removal dates in two of the locations (5 plantings). The experiments were repeated in 2017 and 2018, resulting in 10 site years overall.

Methods

For each experiment location, tarp duration was 3-5 weeks (short), 6-8 weeks (mid), or 10+ weeks (long) prior to a target removal date (RD), either in mid May (RD1) or mid June (RD2). Data represent information prior to crop planting.

Experimental Design

2.1 Freeville, New York, U.S.A.

Research was conducted in a certified organic field at the Cornell University Homer C. Thompson Vegetable Research Farm in Freeville, NY, U.S.. Soils are a well-drained Howard gravelly loam (loamy-skeletal, mixed, active, mesic Glossic Hapludalfs). The field was seeded to oats at 112 $kg \cdot ha^{-1}$ in Aug. 2016/2017. Oats were flail-mowed in Nov. 2016/2017, prior to winterkill, to chop cover crop residues ahead of laying tarps. The experimental design was a randomized complete block design with four replications per treatment. All plots were 3.7 x 3.7 m with two beds that were 1.8 m on center.

Tarps were applied at three time intervals (short, mid, and long durations) prior to two target removal dates: RD1 and RD2 (Table 1). Tarps were cut into 4.9 x 4.9 m pieces to cover plot edges and secured to the soil surface using sand bags.

2.2 Monmouth, Maine, U.S.A.

Research was conducted at the University of Maine Agricultural and Forestry Experiment Station: Highmoor Farm in Monmouth, ME, U.S. in a non-certified organic field. Soils are a Woodbridge fine sandy loam (coarse-loamy, mixed, active, mesic Aquic Dystrudepts) with an 8-15% slope. Prior to planting an oat cover in August 2016 at 112 $kg \cdot ha^{-1}$ with a Great Plains drill (3P605NT Salina, KS, U.S), the field was left fallowed and cultivated using a Perfecta (Perfecta II; Kalida, OH, U.S.) throughout the 2016 growing season. In mid-Dec. 2016/2017, oats were mechanically rolled down in the plots that received an over-wintering tarp treatment in 2017, and flail mowed in all plots in 2018. Plots were 3 x 5.5 m encompassing 3 beds 1.8 m on center that were 3 m long. Tarps were held in place by sand bags and/or burying the edges. Tarps were applied and removed in the same treatments as in Freeville (see Table 1 for dates).

2.3 Riverhead, New York, U.S.A.

Research was conducted in a non-certified organic field at the Long Island Horticultural Research and Extension Center (LIHREC) in Riverhead, NY, U.S.. Soils are a Haven loam (coarse-loamy over sandy or sandy-skeletal, mixed, active, mesic Typic). A cover crop of organic oats (89 $kg \cdot ha^{-1}$) was seeded mid-Sep 2016/2017 after disking the field. The experimental design was a randomized complete block design with four replications per treatment. Tarps were applied in the same treatments as in Freeville. See Table 1 for dates.

Sampling Methods

Soils. Soil temperature sensors (WatchDog B-Series Button Logger) were installed to 20 cm depth in the center of each no-till treatment at the time tarps were applied. Sensors recorded soil temperatures every two hours to generate daily temperature averages until tarp removal. Temperature sensors (Hobo 64K Pendant Temperature Data Logger). Temperature sensors were also applied at a 2.5 cm depth in treatments containing weed seed bags (see *Weed seed assessment*).

Gravimetric soil water content and soil inorganic nitrogen, nitrate, and ammonium were measured (0-15 cm depth) at the time of tarp removal both years, and prior tarp application in 2018. Soil cores (six per treatment) were composited, dried at 45°C, sieved to 2 mm, and analyzed for inorganic nitrogen using 1 N KCl cadmium reduction (Dahnke, 1990) (Brookside Laboratories Inc.; New Bremen, OH, U.S.).

Weed seed germination and degradation. Locally sourced seeds of powell amaranth (*Amaranthus powellii* S. Wats.) and common lambsquarters (*Chenopodium album* L.) were placed in permeable fabric bags (Organza, ULINE S-10647) to test seed germination and degradation under tarps. Each bag was filled with 50 g of soil sieved to 0.5 mm, and 100 seeds of one weed species. Seed bags were buried in a randomly chosen quadrant in the following treatments: no-tarp and short duration tarp treatments for both removal dates (24 plots) and long duration tarp treatments for the RD2 (12 additional plots). All bags were buried 28 March 2018.

Seeds were tested for germination and viability prior to the experiment. Germination rates were 65% and 43% for *A. powellii* and *C. album* respectively. Viability rates were 100% and 99% for *A. powellii* and *C. album* respectively.

Upon tarp removal, all seed bags were taken from the soil, dried at 45°C for 48 hours, and sieved through a 0.5 mm sieve to separate weed seeds from soil. Weed seeds were pressed with forceps to determine viability as an indicator of germination and degradation in the soil, and the ratio of viability was recorded (Sawma and Mohler, 2002).

Cover Crop Residue. Crop residue percent cover of plots was determined using a beaded string method (Shelton and Jasa, 2009). Beads were spaced at a 33 cm interval on a 5 m string (15 beads per 5 m). The string was laid across the plot in two directions and presence/absence of crop residue recorded under each bead (total 30 measures per plot). Data were converted to percent residue.

Precipitation. Daily rainfall and temperature data were collected and summarized from weather stations at each site – the local NEWA station in Freeville, NY and Riverhead, NY (Network for Environment and Weather Applications, 2018), and an on-farm station in Monmouth, ME (HOBO U30, Onset Computer Corporation, Bourne, MA).

Statistical Analysis. Least-squares means were compared using analysis of variance (ANOVA) using RStudio with tarp duration and tillage as fixed effects within the randomized complete block design (RStudio, Inc., Boston, MA, U.S.). Mean separation was by the Tukey-Kramer HSD test at 0.05 level of probability. Prior to running the regression, data were checked for normality of residuals. Data for each location and tarp removal dates were analyzed separately.

Results

Moisture

Tarp use increased soil moisture in the top 15 cm of soil in five out of ten applications across all sites both years (Table 2). For most sites, soil percent moisture values at tarp removal fell between 20-30% and did not vary beyond five percentage points across treatments. In Freeville, tarp use increased soil moisture 4% in RD1 ($p<0.05$) and 6.3% in RD2 ($p<0.01$) in 2018. In Monmouth, tarp use increased soil moisture 2.9% in RD1 ($p<0.01$) in 2017, and between 7.3 and 9.4% ($p<0.05$) for both removal times in 2018. Tarp use did not affect soil moisture in Riverhead. There was no significant difference in soil moisture between tarp durations for any site, removal date, or year.

Ambient precipitation in the weeks prior to tarp removal varied by site and year. In Freeville, precipitation was lower in 2017 than in 2018 (Figure A1). In Monmouth, precipitation was higher in 2018 than in 2017 (Figure A2). In Riverhead, precipitation was higher in 2018 than in 2017, except one heavy rain event in mid-May 2017 (Figure A3).

Temperature

Soil temperature measured at 10 cm fluctuated throughout winter and early spring with no discernible pattern between no-tarp and tarped treatments that were left on the soil over winter (Figure A4-A7). At the time of tarp removal in late spring, however, tarp use significantly increased soil temperatures compared to bare ground ($p<0.05$) in most locations, locations, removal dates, and years (Table 3). Soil temperatures under tarps averaged 1-3°C higher than bare soil. In Monmouth 2018 RD2, tarps increased soil temperature 4.5-5.8°C. The highest average temperature achieved under tarps was 28.7°C in Monmouth 2018 RD2.

Cover crop residue

Tarp use did not decrease cover crop residue as measured by percent cover. Percent residue cover at the time of tarp removal was similar between tarped and untarped plots for RD1 at Freeville and Monmouth both years. For RD2, percent residue was 20-30% higher ($p<0.05$) under tarps as compared with bare ground in 2018 in Freeville, and two to three times higher ($p<0.05$) in 2018 in Riverhead (Table 4). In Monmouth, percent residue was one and a half to three times higher ($p<0.05$) under tarps as compared with bare ground for RD2 in both years.

Nitrogen

Tarp use of any duration increased soil nitrate concentrations as compared with bare ground. In Freeville, nitrate concentrations were four to fourteen times higher under tarps than uncovered soil in 2017 ($p<0.001$), ranging from 2 ppm to 31 ppm, and three and a half to eleven times higher in 2018 ($p<0.001$), ranging from 2 ppm to 22 ppm (Table 5). In Monmouth, nitrate concentrations were one and a half to eighteen times higher under tarps compared with uncovered soil for planting one in 2017 ($p<0.001$), ranging from 2 ppm to 36 ppm, and eight to twenty-one times higher in 2018 ($p<0.001$), ranging from 2 ppm to 42 ppm (Table 5). In Riverhead, concentrations were five to nine times higher in 2017 ($p<0.001$), ranging from 1 ppm to 12 ppm, and six times higher in 2018 ($p<0.001$), ranging from 1 ppm to 6 ppm (**Table 5**). Only one removal time (RD1 in Monmouth in 2017) out of ten had similar nitrate concentrations among bare and tarped treatments.

Nitrate increased with longer tarp duration in all locations, removal dates, and years (R^2=0.74-0.91) except RD1 2017 in Maine. Concentrations reached up to 42 ppm under long duration tarps in Monmouth and 31-36 ppm under long duration tarps in Freeville. Pre-tarp nitrate concentrations were not different among tarped and untarped treatments (Table 5). Soil ammonium was not affected by tarps except for RD2 in 2017 in Monmouth, in which it was decreased by 27-45% with tarp use ($p<0.01$) (Table A1).

Weed seed germination and degradation

Survivability of *A. powellii* seeds was inconsistent across treatments, indicating unpredictable seed germination and degradation. The number of surviving seeds by the end of the tarping period increased significantly from 73% in bare soil to 82% under short duration tarps in RD1 ($p<0.05$) (Table A2). In RD2, short duration tarps did not impact seed survivability, but long duration tarps increased the number of surviving seeds from 61% to 70% ($p<0.05$) compared with bare soil. Tarps had no effect on *C. album* survivability, which averaged 86% (Table A2).

Discussion

Moisture

Despite daily and yearly fluctuations in precipitation at the time of tarp application, throughout tarp duration, and at tarp removal, soil moisture at the time of tarp removal was higher under tarps compared with bare ground in five of the experiments (Table 4). Amount of precipitation during tarp duration did not impact soil moisture differences between tarp treatments and bare ground. For example, in Monmouth 2018 RD2, 23 cm of rain fell between long duration tarp application and tarp removal. Mid duration tarps received 10 cm of rain, and short duration tarps received 8 cm of rain with the tarp in place. Despite these differences, there was no difference in moisture among tarp treatments, and soil moisture under tarps was greater than bare ground. This fits with other studies' results that soil under black tarps has more consistent moisture than uncovered soil (Lounsbury et al., 2018).

Plastic mulch films increase soil moisture compared with bare ground (Fritz, 2012, Gu et al., 2018; Kasirajan and Ngouajio; Fan et al., 2017; Zhang et al., 2017). Tarps may slow the rate of water evaporation from the soil, and in some cases allow air and water flow on the soil surface to some degree. Water may move laterally under tarps during rain events, and be prevented from evaporating during dry periods by tarps.

Temperature

Soil temperature under tarps only increased compared with bare ground later in the season, when outside temperatures reached 15°C or more (Figure A4-7). This is inconsistent with studies showing decreased temperatures under black tarps in June in New Hampshire compared with uncovered treatments (Lounsbury et al., 2018). Clear plastic sheets and black mulch film both increase soil temperature (Abu-Gharbieh et al., 1988; Canul-Tun et al., 2017; Filipovic et al., 2016; Öz, 2018; Ramakrishna et al., 2006). Black plastic films absorb shortwave radiation from the sun and transfers that heat to the soil through thermal conductivity (Ham et al., 1993; Ham and Kluitenberg, 1994). Plastic to soil contact is vital to facilitate this heat transfer (Liakatas et al., 1985) and may explain condradictory results between this experiment and Lounsbury et al. 2018. It is possible that different species of cover crops or methods of mowing could influence tarp-soil contact and affect the ability of tarps to heat the soil. A smoother surface likely facilitates higher temperature increases in the soil under tarps.

Soil moisture and rainfall events during tarp duration may also affect soil temperatures under tarps compared with bare ground. There was a positive correlation between soil moisture and temperature at the time of removal in three of ten site years ($p<0.05$) and a similar trend in two others ($p<0.1$). Higher soil moisture may increase temperature under tarps at the time of their removal.

Soil temperatures under tarps were 1-3°C higher than bare soil at the time of removal, though the increase was 1-3°C. This is consistent with the 1-6°C increase in average soil temperature under black tarps in Maine (Birthisel, 2018). When a mulch film is used in season, other research has found an average 3-6°C increase under black film and 10°C+ increase under clear plastic (Canul-Tun et al., 2017; Filipovic et al., 2016; Ramakrishna et al., 2006). Farmers use both clear plastic and mulch film during the warmest months of the year whereas farmers apply tarps earlier in the season. The seasonal timing of tarps limits the likely temperature gain compared with bare ground. The combination of warmer soil temperatures and possible moderated soil moisture after tarping, however, may support planting a few days or weeks earlier than in bare ground.

Crop residue

Tarp use in these experiments conserved flail-mowed or rolled oat crop residue. This is in contrast to the ovservations of black tarps decreasing roller-crimpered rye/hairy vetch cover crop residue biomass compared with no-tarp treatments in New Hampshire (Lounsbury et al., 2018).

The observed increase in rye/hairy vetch crop residue degradation was attributed to less fluctuation in soil temperature and moisture to create a more stable environment for microbes (Lounsbury et al., 2018). Roller-crimpered cover crop residue is mechanically crushed against the soil, whereas flail-mowed residue sits on the soil surface. It is possible that using a roller-crimper method to kill a cover crop increases degradation under tarps more efficiently than using a flail-mowing method due to increased soil to residue contact. Tarp removal was later in the summer in New Hampshire experiments than in this experiment, and higher ambient temperatures may have increased crop residue degradation.

While the increased moisture and temperatures under tarps may promote microbial activity, buried crop residue decomposes 3.4 times faster than residue on the soil surface (Beare et al., 1993), which may not be as accessible to microbes. Decreased exposure to rainfall, wind, and sunlight under tarps may have slowed the degradation of surface residue in this experiment.

Farmers observe an increase in crop residue degradation, but often precede tarp application with tillage or compost. For these trials, tarps were applied directly over flail-mowed oat residue with no soil incorporation or amendments added prior to tarp application. Applying amendments, irrigation, or tillage before tarp application may promote the degradation of residue.

Nitrogen

Soil nitrate concentration was increased up to 21 times by tarp duration over six months (Table 5). Plastic mulch film increases nitrate concentrations in the soil (Teasdale, 2000), but this is during the cropping season, not prior to planting as with tarps in this research. Nitrate is a highly soluble and easily leached compound. Tarps cover the soil during a time when no plants are present to take up nitrate from the soil. Tarps likely reduce leaching losses by rainfall and snowmelt. Longer tarp durations shield the soil from rainfall for a longer period, allowing more nitrate to remain in the soil from the time of tarp application. It is also possible that tarps prevent the pooling of water on the soil surface, decreasing risk of anaerobic conditions and denitrification.

Increased soil temperature and moisture under tarps may promote microbial activity, increasing the rate of nitrification in the soil. In four of ten site years, there was a significant correlation between increased soil moisture and increased nitrate concentrations at the time of tarp removal ($p<0.05$). Where cumulative precipitation data were taken throughout tarp duration, there was a positive correlation between precipitation and nitrate concentrations at three of seven site years ($p<0.05$), and a similar trend in three of the other site years ($p<0.1$). There was little correlation between nitrate concentrations and soil temperature at the time of tarp removal, except for a positive correlation in Monmouth in 2018 ($p<0.01$), but a high correlation with cumulative growing degree days (base 4.4°C) from the last three weeks of tarp duration where data was taken (Freeville and Monmouth 2018 both plantings) ($p<0.05$).

This suggests that moisture and temperature dynamics under tarps influence nitrate concentrations in the soil. Soil moisture and temperature had less fluctuation under black tarps compared with bare ground in New Hampshire (Lounsbury et al, 2018). Because soil microbes respond favorably to increased soil moisture and temperature (Brockett et al., 2012) and soil conditions with less fluctuation (Biederbeck and Campbell, 1973), tarps may increase microbial activity and nitrification.

Weed seed germination and degradation

Tarps did not have a clear impact on weed seed germination or degradation. The number of surviving seeds at the end of the tarping period indicated the number of seeds that did not germinate or degrade in the soil (predation could not be measured with the mesh bag method). *A. powellii* seed survivability increased under some tarp treatments, indicating that fewer seeds germinated or degraded in the soil. This is in contrast to studies showing increases in redroot pigweed (*Amaranthus retroflexus* L.) germination in the absence of light when nitrate concentrations and temperature increase (20°C) (Gallagher, 1998). Black plastic film increases redroot pigweed germination due to increased soil nitrate concentrations (Teasdale, 2000). Despite increased soil nitrate concentrations and temperatures under tarps, *A. powellii* seed germination did not increase under tarps compared with bare ground.

C. album surivability was unaffected by tarping, indicating that tarps do not influence the germination and degradation of this species. *C. album* germination does not respond drastically to nitrate concentrations (Saini et al., 1985), and often shows inconsistent emergence response to changing environmental cues caused by methods such as tillage (Chauhan and Johnson, 2010).

White thread-stage weed seedlings were observed under short duration tarps for 2018 RD1 in Freeville. These weed seedlings died within several hours of tarp removal (14 May 2018). At this time, weed seed germination for species such as chickweed (*Stellaria media* L.) and pigweed (*A. powellii*) is high (Schonbeck, 2014; Wilen, 2006). RD2 tarps were removed mid June and did not have any white thread-stage seedlings visible under tarps. The short duration tarp for this planting was laid over emerged and mature weeds rather than bare soil. All emerged weeds were dead by the time of removal.

Farmers also observe weed seedling emergence under tarps early in the season (Nina Saeli, personal communication), though this is inconsistent. Seed germination depends upon a number of complex factors, and varies by species (Chauhan and Johnson, 2010). Some weed species do germinate under tarps, but the effects of tarps on germination, dormancy, and degradation are still unclear.

Conclusions

Tarps increase soil moisture and temperature in the weeks prior to planting a crop. This may enable farmers to plant earlier in the season when using tarps. There was a correlation between increased moisture, temperature, and nitrate concetrations. Nitrate concentrations increase with longer tarp durations, reaching average concentrations up to 42 ppm compared with bare ground concentrations of 2 ppm. Tarps may reduce leaching, and the increased moisture and temperature under tarps may increase nutrient mineralization.

Tarp impact on cover crop degradation and weed seed germination remains unclear. Weed seed dynamics under tarps vary by species, and likely depend upon complex conditions and interactions varying with what time of season a tarp is on the ground and what species are present in the seed bank. Some weed species do germinate under tarps, and with proper timing, farmers may use tarps to manage the weed seed bank.

Tarps did not increase crop residue degradation, decreasing it in three site years. This may negatively impact the ease of planting in high-residue systems.

Further research is needed to analyse how soil temperature and soil moisture fluctuate throughout the duration of tarp application compared with bare ground. Comparison of crop degradation under different cover crop and soil management systems is needed to assess the impact of tarps on residue degradation. More information is needed on the dynamics of nutrients and microbial activity under tarps in varying temperature and moisture conditions. Analysis of weed seed bank dynamics under tarps is needed to inform management practices of using tarps for stale seedbed and other forms of weed management.

Table 1. Experiment dates for Freeville, NY, Monmouth, ME, and Riverhead, NY for two tarp removal dates in 2017 and 2018. Removal date one (RD1) and removal date two (RD2) indicate early vs. late-season tarp removal.

	Freeville				Monmouth				Riverhead	
	2017		2018		2017		2018		2017	2018
	RD1	RD2	RD1	RD2	RD1	RD2	RD1	RD2		
Cover Crop Planted	25 Aug.	25 Aug.	25 Aug.	25 Aug.	Mid Aug.	Mid Aug.	Mid Aug.	Mid Aug.	9 Sept.	26 Sept.
Long duration tarp	15 Nov.	30 Mar.	17 Nov.	2 Apr.	8 Dec.	27 Apr.	21 Nov.	10 Apr.	19 Jan.	21 Nov.
Mid duration tarp	30 Mar.	26 Apr.	2 Apr.	30 Apr.	13 Apr.	17 May	13 Apr.	21 May	11 Apr.	13 Apr.
Short duration tarp	20 Apr.	18 May	23 Apr.	21 May	3 May	9 June	15 May	11 June	2 May	4 May
Tarps removed	16 May	16 June	14 May	11 June	8 June	6 July	5 June	11 July	1 June	29 May

Table 2. Gravimetric soil moisture (%) in the top 15 cm of soil post-tarp removal for Freeville, NY, Monmouth, ME, and Riverhead, NY separated by tarp removal date (RD1, RD2) and year.

		2017		2018	
		RD1[v]	RD2[w]	RD1[x]	RD2[y]
Freeville	Untarped	20.3	21.8	22.8	21.0
	Tarped	21.3	22.6	26.8	27.3
		NS[z]	NS	*	**
Monmouth	Untarped	30.5	31.4	17.1	17.1
	Tarped	33.4	36.2	24.4	26.5
		**	NS	*	***
Riverhead	Untarped	16.3	--	10.7	--
	Tarped	16.3	--	11.0	--
		NS	--	NS	--

[v]Data taken in Freeville: 16 May 2017, Monmouth: 8 June 2017, Riverhead: 1 June 2017

[w]Data taken in Freeville: 16 June 2017, Monmouth: 6 July 2017; Riverhead had only one planting

[x]Data taken in Freeville: 14 May 2018, Monmouth: 5 June 2018, Riverhead: 29 May 2018

[y]Data taken in Freeville: 11 June 2018, Monmouth: 11 July, 2018, Riverhead had only one planting

[z]Mean separation by Tukey HSD at $P \leq 0.05$.

[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 3. Soil temperature (C) at a 20 cm depth the day before tarp removal for Freeville, NY, Monmouth, ME, and Riverhead, NY separated by tarp removal date (RD1, RD2) and year.

		2017		2018	
	Tarp duration	RD1[v]	RD2[w]	RD1[x]	RD2[y]
	None	11.8 b[z]	20.7 b	15.6 a	18.6 b
	Short	13.2 a	21.3 ab	15.8 ab	20.4 a
Freeville	Mid	13.3 a	21.4 a	16.1 ab	20.7 a
	Long	13.3 a	21.6 a	16.4 b	20.9 a
		**	*	*	***
	None	19.1 b	24.1	15.8 b	22.9 b
	Short	20.8 a	25.6	17.1 a	28.0 a
Monmouth	Mid	20.1 ab	25.5	17.1 a	28.7 a
	Long	20.4 ab	25.0	16.8 a	27.4 a
		*	NS	***	***

[v]Data taken in Freeville: 15 May 2017, Monmouth: 7 June 2017
[w]Data taken in Freeville: 15 June 2017, Monmouth: 5 July 2017
[x]Data taken in Freeville: 13 May 2018, Monmouth: 4 June 2018
[y]Data taken in Freeville: 10 June 2018, Monmouth: 10 July, 2018
[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 4. Surface residue percent cover the day of tarp removal for Freeville, NY, Monmouth, ME, and Riverhead, NY separated by tarp removal date (RD1, RD2) and year.

		2017		2018	
		RD1[v]	RD2[w]	RD1[x]	RD2[y]
Freeville	None	65	54	79	51 b[z]
	Short	59	58	81	65 a
	Mid	62	53	78	67 a
	Long	77	60	80	61 ab
		NS	NS	NS	*
Monmouth	None	78	44 b	91	30 b
	Short	70	86 a	80	92 a
	Mid	71	80 a	77	75 a
	Long	74	67 a	88	77 a
		NS	*	NS	***
Riverhead	None	78 ab	--	6 c	--
	Short	68 b	--	12 b	--
	Mid	77 ab	--	15 ab	--
	Long	79 a	--	16 a	--
		*	--	***	--

[v]Data taken in Freeville: 16 May 2017, Monmouth: 8 June 2017, Riverhead: 1 June 2017
[w]Data taken in Freeville: 16 June 2017, Monmouth: 6 July 2017; Riverhead had only one planting
[x]Data taken in Freeville: 14 May 2018, Monmouth: 5 June 2018, Riverhead: 29 May 2018
[y]Data taken in Freeville: 11 June 2018, Monmouth: 11 July, 2018, Riverhead had only one planting
[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 5. Soil N-NO_3 concentrations (ppm) post-tarp in the top 15 cm of soil for Freeville, NY, Monmouth, ME, and Riverhead, NY separated by tarp removal date (RD1, RD2) and year.

		2017		2018	
		RD1[v]	RD2[w]	RD1[x]	RD2[y]
Freeville	None	2 a	2.9 c	2 c	2 b
	Short	8 a	18 b	7 b	14 a
	Mid	8 a	25 ab	10 b	15 a
	Long	28 b	31 a	22 a	17 a
		***	***	***	***
Monmouth	None	10	2 c	2 b	2 b
	Short	16	20 b	16 a	37 a
	Mid	22	29 ab	22 a	42 a
	Long	18	36 a	24 a	42 a
		NS	***	***	***
Riverhead	None	1 c	--	1 a	--
	Short	7 ab	--	--	--
	Mid	10 b	--	6 b	--
	Long	12 a	--	--	--
		***	--	***	--

[v]Data taken in Freeville: 16 May 2017, Monmouth: 8 June 2017, Riverhead: 1 June 2017

[w]Data taken in Freeville: 16 June 2017, Monmouth: 6 July 2017; Riverhead had only one planting

[x]Data taken in Freeville: 14 May 2018, Monmouth: 5 June 2018, Riverhead: 29 May 2018

[y]Data taken in Freeville: 11 June 2018, Monmouth: 11 July, 2018, Riverhead had only one planting

[z]Mean separation by Tukey HSD at $P \leq 0.05$.

[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 5. Soil N-NO_3 concentrations (ppm) post-tarp in the top 15 cm of soil for Freeville, NY, Monmouth, ME, and Riverhead, NY separated by tarp removal date (RD1, RD2) and year.

		2017		2018	
		RD1[v]	RD2[w]	RD1[x]	RD2[y]
Freeville	None	2 a	2.9 c	2 c	2 b
	Short	8 a	18 b	7 b	14 a
	Mid	8 a	25 ab	10 b	15 a
	Long	28 b	31 a	22 a	17 a
		***	***	***	***
Monmouth	None	10	2 c	2 b	2 b
	Short	16	20 b	16 a	37 a
	Mid	22	29 ab	22 a	42 a
	Long	18	36 a	24 a	42 a
		NS	***	***	***
Riverhead	None	1 c	--	1 a	--
	Short	7 ab	--	--	--
	Mid	10 b	--	6 b	--
	Long	12 a	--	--	--
		***	--	***	--

[v]Data taken in Freeville: 16 May 2017, Monmouth: 8 June 2017, Riverhead: 1 June 2017

[w]Data taken in Freeville: 16 June 2017, Monmouth: 6 July 2017; Riverhead had only one planting

[x]Data taken in Freeville: 14 May 2018, Monmouth: 5 June 2018, Riverhead: 29 May 2018

[y]Data taken in Freeville: 11 June 2018, Monmouth: 11 July, 2018, Riverhead had only one planting

[z]Mean separation by Tukey HSD at $P \leq 0.05$.

[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Works Cited

Abu-Gharbieh, W.I., H. Saleh, and H. Abu-Blan. 1988. Use of black plastic for soil solarization and post-plant mulching. Plant Protection Dept., Faculty of Ag., Univ. of Jordan, Amman, Jordan.

Beare, M.H., D.C. Coleman, B.R. Pohlad, and D.H. Wright. 2010. residue placement and fungicide effects on fungal communities in conventional and no-tillage soils. Soil Sci. Soc. Amer. *J.* 57(2): 392-399.

Biederbeck, V.O. and C.A. Campbell. 2010. Soil microbial activity as influenced by temperature trends and fluctuations. Can. J. of Soil Sci. 53:363-376.

Birthisel, S.K.. 2018. Multi-tactic ecological weed management in a changing climate. Univ. of Maine, Orono, PhD Diss. 2928.

Brockett, B.F.T., C.E. Prescott, and S.J. Grayston. 2012. Soil moisture is the major factor influencing microbial community structure and enzyme activities across seven biogeoclimatic zones in Western Canada. Soil Biol. and Biochem. 44:9-20.

Candido, V., D. Castronuovo, V. Miccolis, and T. D'Addabbo. 2011. Weed control and yield response of soil solarization with different plastic films in lettuce. Scientia Horticulturae 130:491-497.

Canul-Tun, C.E., L. Ibarra-Jimenez, L.A. Valdez-Aguilar, A.J. Lozano-del Rio, A. Cardenas-Flores, A. Zermeno-Gonzalez, C.J. Lozano-Cavazos, J.H. Valenzuela-Soto, and V. Torres-Olivar. 2017. Influence of colored plastic mulch on soil temperature, growth, nutrimental status, and yield of bell pepper under shade house conditions. J. Plant Nutr. 40(8): 1083-1090.

Chauhan, B.S. and D.E. Johnson. 2010. the role of seed ecology in improving weed management strategies in the tropics. Adv. in Agron. 105.

Dahnke, W.C.. 1990. Testing soils for available nitrogen. P. 120-140. In: R.L. Westerman (ed.) Soil testing and plant analysis. Soil Sci. Soc. Am. Book Series 3, ASA, Madison, WI.

Egley, G.H.. 1983. Weed seed and seedling reductions by soil solarization with transparent polyethylene. Weed Sci. 31.

Fan, Y., L. Tong, R. Ding, S. Kang, S. Li, T. Du, and X. Hao. 2017. Plastic mulch decreases available energy and evapotranspiration and improves yield and water use efficiency in an irrigated maize cropland. Ag. Water Mgt. 179:122–31.

Filipovic, V., D. Romic, M. Romic, J. Borosic, L. Filipovic, F.J.K. Mallmann, and D.A. Robinson. 2016. Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: Experimental results and a modeling study. Ag. Water Mgt. 176:100–110.

Fritz, V.A.. 2012. Plastic mulches: Benefits, types, and sources. Minnesota High Tunnel Production Manual for Commercial Growers. 2nd ed. Univ. Minn.

Gallagher, R.S. and J. Cardina. 1998. Phytochrome-mediated amaranthus germination. II. Development of very low fluence sensitivity. Weed Sci. 46(1):53–58.

Gu, Y-J., C-L. Han, J-W. Fan, X-P. Shi, M. Kong, X-Y. Shi, K.H.M. Siddique, Y-Y. Zhao, and F-M. Li. 2018. Alfalfa forage yield, soil water and P availability in response to plastic film mulch and P fertilization in a semiarid environment. Field Crops Res. 215:94–103.

Ham, J.M., G.J. Kluitenberg, and W.J. Lamont. 2019. Optical properties of plastic mulches affect the field temperature regime." J. Amer. Soc. Hort. Sci. 118(2):188–93.

Ham, J.M. and G.J. Kluitenberg. 1994. Modeling the effect of mulch optical properties and mulch-soil contact resistance on soil heating under plastic mulch culture. J. Agr. Forest Meteorol. 71:403-424.

Kanaan, H., S. Frenk, M. Raviv, S. Medina, and D. Minz. 2018. Long and short term effects of solarization on soil microbiome and agricultural production. Appl. Soil Ecol. 124:54-61.

Kasirajan, S. and M. Ngouajio. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agron. for Sustainable Dev. 32:501-529.

Khan, M.A., R. Khan, H. Khan, H.U. Shah, K.B. Marwat, A. Amin, and A. Nawaz. 2012. Soil solarization: An organic weed-management approach in cauliflower. Commun. Soil Sci. Plant Analysis 43(13):1847–60.

Liakatas, A., J.A. Clark, and J.L. Monteith. 1986. Measurements of the heat balance under plastic mulches part I: Radiation balance and soil heat flux. Agr. Forest Meteorol. 36:227-239.

Linke, K.H.. 1994. Effects of Soil Solarization on Arable Weeds under Mediterranean Conditions: Control, Lack of Response or Stimulation. Crop Protection 13(2):115-120.

Lounsbury, N.P., N.D. Warren, S.D. Wolfe, and R.G. Smith. 2018. Investigating tarps to facilitate organic no-till cabbage production with high-residue cover crops. Renewable Ag. Food Systems. p. 1–7.

Network for Environment and Weather Applications. 2018. [Online]. Available at: newa.cornell.edu

Öz, H.. 2018. A new approach to soil solarization: Addition of biochar to the effect of soil temperature and quality and yield parameters of lettuce (*Lactuca sativa L. Duna*). Scientia Horticulturae 228:153–61.

Ramakrishna, A., H.M. Tam, S.P. Wani, and T.D. Long. 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam." Field Crops Res. 95:115-125.

Saini, H.S., P.K. Bassi, and M.S. Spencer. 2008. Seed germination in *Chenopodium album* l: Relationships between nitrate and the effects of plant hormones. Plant Physiol. 77:940-943.

Sawma, J.T. and C.L. Mohler. 2006. Evaluating seed viability by an unimbibed seed crush test in comparison with the tetrazolium test 1. Weed Tech. 16(4):781-786.

Samtani, J.B., J. Derr, M.A. Conway, and R.D. Flanagan III. 2017. Evaluating soil solarization for weed control and strawberry (*Fragaria xananassa*) yield in annual plasticulture production. Weed Tech. 31:455-463.

Schonbeck, M.. 2019. Weed profile: Pigweeds (*Amaranthus spp.*). eOrganic. 10 Mar. 2014. < https://articles.extension.org/pages/65208/weed-profile:-pigweeds-amaranthus-spp>

Shelton, D.P. and P.J. Jasa. 2009. Estimating percent residue cover using the line-transect method. NebGuide. University of Nebraska, Lincoln. <http://extensionpublications.unl.edu/assets/pdf/g1931.pdf>

Teasdale, J.R. and C.L. Mohler. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci. 48(3):285-392.

Wilen, C.A.. 2006. Pests in gardens and landscapes: Chickweeds. Univ. California Statwide IPM Program. San Diego County. Apr. 2006.

Yu, Y.Y., N.C. Turner, Y.H. Gong, F.M. Li, C. Fang, L.J. Ge, and J. S. Ye. 2018. Benefits and limitations to straw- and plastic-film mulch on maize yield and water use efficiency: A meta-analysis across hydrothermal gradients. European J. Agron. 99:138-147.

Zhang, Y-L., C.C. Shock, F-X. Wang, J-T. Qin, K-J. Yang, S-Z. Kang, and S-E. Li. 2017. Influence of Different Plastic Film Mulches and Wetted Soil Percentages on Potato Grown under Drip Irrigation. Ag. Water Mgt. 180:160–71.

Chapter 3: Reusable opaque tarps control weeds and increase yield in organic reduced tillage system for beets

Introduction

Farmers commonly use intensive tillage in U.S. vegetable production to prepare seedbeds, incorporate crop residue, and remove weeds. Intensive tillage, however, decreases long-term soil health, causing compaction, loss of structure, and loss of organic matter. Reducing soil disturbance over time leads to improved soil aggregate stability, water retention, and infiltration (Arshad et al.,1999; Mendoza et al., 2008; Power et al., 1986). Reduced till soils also have greater organic matter, nutrient accumulation, and stimulation of biological activity (Beare et al., 1997; Franzluebbers, 2002; Gupta and Germida, 1998; Hungria et al., 2009; Tebrügge and Düring, 1999).

Reduced tillage in organic systems often results in lower yields compared with organic conventional tillage (Halde et al., 2015; Leavitt et al., 2011). Weed management is one of the greatest concerns with reduced tillage systems. Weed density and biomass are higher in reduced-till systems than in conventional-till systems (Campiglia et al., 2017; Cavalaris and Gemtos, 2002; Nakamoto et al., 2006). Many conventional farms increase use of herbicides when reducing tillage (Buhler et al., 1994), but this is not an option for organic growers.

With proper management tactics, reduced tillage can increase yields in organic vegetables. Cover crop residue left on the surface of the soil in reduced tillage systems releases nutrients into the soil (Sharifi et al., 2008), increases soil moisture retention (Power et al., 1986; Laufer et al., 2016), and increases crop growth (Laufer et al., 2016; Tebrügge and Düring, 1999; Wilhelm et al., 1986). In organic vegetable systems, roller-crimpered cover crops significantly reduce weed pressure and increase crop competitiveness with weeds (Altieri et al., 2011; Canali et al., 2013; Ciaccia et al., 2016).

Conversely, crop residue can inhibit crop growth by lowering soil temperature (Johnson and Lowery, 1985; Jokela and Nair, 2016b), thereby reducing nutrient availability, and by decreasing nitrogen concentrations in the soil, likely by preventing timely release of nitrogen from crop residue when not incorporated into the soil (Jokela and Niar, 2016b; Leavitt et al., 2011).

Crop residue can also inhibit machinery used for direct seeding crops. Growing direct-seeded crops in organic, reduced-till vegetable systems is a significant challenge. It is difficult for mechanical seeders to function in high residue and high weed environments, and no-till seeders can be a significant investment for small-scale farmers. For this experiment, we chose to grow direct-seeded table beets to assess yield impacts of tarps. Beets are poor competitors with weeds when they first emerge, and early-season weed control is crucial for a successful crop. Soil compaction caused by tractor traffic increases soil strength, and can interefere with seeders as well as inhibit secondary growth of taproots (Marinello et al., 2017; Yapa et al., 1988) without tillage to loosen the soil. Conventional sugar beet yield is often decreased by reduced till systems compared with conventional till systems (Cavalaris and Gemtos, 2002; Koch et al., 2009). In contrast, while sugar beet yield across multiple European countries decreases in no-till systems, yields in reduced-till systems are comparable to that of conventional-till systems (Van den Putte et al., 2010). To the best of our knowledge, no studies evaluate organic table beets in reduced-till systems.

Tarp effect on crop residue is unclear. Tarps do not decrease winter-killed oat crop residue compared with bare ground treatments, even preserving it in some cases (Rylander et al., 2019). Tarps do, however, significantly decrease residue of a roller-crimpered rye/hairy vetch cover crop compared with both bare ground and clear plastic (Lounsbury et al., 2018).

The effect of tillage on weeds is species-specific, dependent upon the germination requirements, life cycle, and dispersal mechanisms of individual species (Chauhan et al., 2012). Tillage can induce dormancy of annual weed seeds by burying them, and kill emerged annual weeds by chopping them and leaving them to dry out on the soil surface, but tillage may also bring up new weed seeds (Nakamoto et al., 2006).

The application of temporary, impermeable tarps to the soil surface prior to cash crop planting is an alternative weed management strategy recently used by some organic vegetable farmers. Tarps are durable, opaque, 0.15 mm polyethylene plastic impermeable to water. Tarps cover multiple crop rows at a time and last many years. This is in contrast to black plastic films, which remain under crops during the growing season and are not reused beyond a single season (Abu-Gharbieh et al., 1988).

Synthetic soil covers, including plastic, are already used in organic and conventional agriculture. In the case of soil solarization, transparent plastic sheets are temporarily placed on the soil at times of intense sunlight and temperatures. Solarization reduces weed pressure and increases yields in a numerous crops (Candido et al., 2011; Egley, 1983; Khan et al., 2012; Kanaan et al., 2018; Link, 199; Samtani et al., 2017). Soil temperatures increase 10°C or higher compared with bare ground, ranging from 40°C to 65°C, to kill weeds, weed seeds, and other pests (Abu-Gharbieh et al., 1988; Egley, 1983; Öz, 2018). Solarization is thus not reliable in climates lacking appropriately high and consistent temperatures.

Black tarps kill all emerged weeds within two to three weeks (Birthisel, 2018; Lounsbury et al., 2018). Weed seeds germinate in response to changes in light, temperature, nutrients, soil moisture. In reduced till systems, 50-85% of the weed seed bank is in the upper 5 cm of soil (Chauhan et al., 2006; Clements et al., 1996). Tarps increase soil nitrate, moisture, and temperature in the top 15 cm of soil (Rylander, 2019), creating a soil environment favorable to seed germination. Depending on the duration and timing of tarp use, and soil disturbance prior to tarp application, tarps have the potential to promote fatal germination of some weeds by blocking light from emerged seedlings. The effect of tarps on weed seeds is likely species specific. Survivability of *Amaranthus powellii* seeds in the top 1 cm of soil is higher under tarped compared with uncovered soil, indicating a lower germination and degradation rate under tarps, but tarps have no effect on *Chenopodium album* seed germination and degradation (Rylander, 2019).

Tarps may reduce farmers' reliance on tillage by providing a number of similar services to farmers. Tarps suppress early-season weeds prior to crop planting and create a weed-free seedbed in which to plant. Tarping combined with reduced tillage can preserve prepared planting beds over weeks or months, and may allow earlier tillage or planting in the spring by keeping the soil warmer and at a moisture level conducive to tillage equipment.

Tarping may also be an alternative to tillage or tool to reduce tillage in killing and degrading cover crops. In New Hampshire, tarps kill a roller-crimpered rye-hairy vetch cover crop within two weeks, decreasing residue cover by over 1100 $kg \cdot ha^{-1}$ compared with bare ground and clear plastic (Lounsbury et al., 2018). In contrast, tarps in New York do not decrease winter-killed oat residue compared with bare ground (Rylander, 2019). The efficacy of increased crop residue degradation under tarps is unclear, and may depend upon the cover crop species, timing of cover crop kill, and environmental conditions such as temperature and rainfall.

The objective of this experiment was to evaluate the ability of black plastic tarps to suppress weeds in a direct seeded summer beet crop under different tillage systems. The effect of tarps on beet yield and the mechanisms behind weed suppression were also assessed.

Methods

For all locations, tarp duration was either: 3-5 weeks (short), 6-8 weekd (mid) or 10+ weeks (long) prior to a target planting date in mid May or mid June. Tillage treatments were classified as: 1) no-till (planter disturbance only), 2) reduced-till (3-8 cm), and 3) conventional-till (10-20 cm).

Experimental Design

2.1 Freeville, New York, U.S.A.

Research was conducted in a certified organic field at the Cornell University Homer C. Thompson Vegetable Research Farm in Freeville, NY, U.S.. Soils are a well-drained Howard gravelly loam (loamy-skeletal, mixed, active, mesic Glossic Hapludalfs). The field was seeded to oats at 112 kg·ha^{-1} in Aug. 2016/2017. Oats were flail-mowed in Nov. 2016/2017, prior to winterkill, to chop cover crop residues ahead of laying tarps. The experimental design was a randomized complete block design with four replications per treatment. All plots were 3.7 x 3.7 m with two beds that were 1.8 m on center.

Tarps were applied at three time intervals (short, mid, and log duration) prior to two target planting dates of beets [*Beta vulgaris* L. cv. Boro]: mid-May and mid-June (Table 1). Tarps were cut into 4.9 x 4.9 m pieces to cover plot edges and secured to the soil surface using sand bags. Tarps were left in place and removed immediately prior to planting operations. Three different tillage practices were applied after tarp removal: no-till, reduced-till, and conventional-till. A no-till planting aid, consisting of narrow cultivator shoes mounted on a tractor tool bar, was used to prepare in-row areas for no-till seeding. Conventional-till (approx. 10.2 cm deep), was achieved using a 1.8 m tiller (Maschio B 180-C; DeWitt, IA, U.S.). Reduced-till treatments (approx. 2.5 cm deep) were created using a full-width seeder with cutting discs and a roller (Kasco KED-72; Shelbyville, IA, U.S.).

Approximately 23 kg of a pelletized chicken compost 5N-4P-3K (Kreher Family Farms; Clarence, NY, U.S.) was broadcast-applied to all treatments prior to planting based on soil test recommendations. 'Boro' beets were seeded at a target of 14.6 kg·ha^{-1} for a plant population of 33 seeds·m^{-2}, or 717,593 seeds·ha^{-1} using a seeder (Monosem MS 4-Row Planter; Edwardsville, KS, U.S.), four rows per bed at 38 cm between row spacing.

Beds were cultivated 10 and 20 days after planting using a tractor cultivator with 8" beet knives (Saukville 2001 DDL; Newburg, WI, U.S.). In 2017, no-till treatments were maintained with no cultivation. No hand weeding was applied to treatments either year.

2.2 Monmouth, Maine, U.S.A.

Research was conducted in a non-certified organic field at the University of Maine Agricultural and Forestry Experiment Station: Highmoor Farm in Monmouth, ME, U.S. Soils are a Woodbridge fine sandy loam (coarse-loamy, mixed, active, mesic Aquic Dystrudepts) with an 8-15% slope. Prior to planting an oat cover in August 2016 at 112 $kg{\cdot}ha^{-1}$ with a Great Plains drill (3P605NT Salina, KS, U.S), the field was left fallow and cultivated using a Perfecta (Perfecta II; Kalida, OH, U.S.) throughout the 2016 growing season. In mid-Dec. 2016/2017, oats were mechanically rolled down in the plots that received an over-wintering tarp treatment. Tarps were held in place by sand bags and/or burying the edges. Plots were 3 x 5.5 m encompassing 3 beds 1.8 m on center that were 3 m long. Tarps were applied in the same treatments as in Freeville (see Table 1 for dates).

Tarp removal and tillage treatments were the same as Freeville but with no mid-season cultivation. Tillage treatments were done with a BCS two-wheeled walk-behind tractor (732GX11; Portland, Oregon, U.S): conventional till (15-20 cm), reduced till (5-8 cm). Fifty-six $kg{\cdot}ha^{-1}$ of N was broadcasted using Pro-Gro 5N-3P-4K fertilizer (North Country Organics; Bradford, VT, U.S.) prior to tillage and planting. 'Boro' beet was planted by hand approximately 2.5 cm apart with 38 cm between row spacing. However, due to inconsistent seeding, plant density was much higher intra-row in some plots.

2.3 Riverhead, New York, U.S.A.

Research was conducted in a non-certified organic field at the Long Island Horticultural Research and Extension Center (LIHREC) in Riverhead, NY, U.S. Soils are a Haven loam (coarse-loamy over sandy or sandy-skeletal, mixed, active, mesic Typic). A cover crop of organic oats (89 $kg \cdot ha^{-1}$) was seeded mid-Sep 2016/2017 after disking the field. The experimental design was a randomized complete block design with four replications per treatment. Tarps were applied in the same treatments as in Freeville. See Table 1 for dates.

Plots that received tillage were prepared for planting on early June 2017/2018 by running a 1.5 m gear-driven rototiller over the planting area at approximately 5 cm depth (King Kutter Inc., Winfield, AL). Fertilizer was applied to all plots in the form of Pro-Gro granular fertilizer (5N-3P-4K) at a rate of 890 $kg \cdot ha^{-1}$. 'Boro' beets were directly seeded into the ground using a MaterMacc vacuum seeder (MS8100, San Vito al Tagliamento, Italy) at a rate of approximately 49 $seed \cdot m^{-1}$. Drip-tape irrigation was placed in beet plots mid-June 2017/2018. Plots were divided into two sections: one to be weeded periodically by hand throughout the growing season and one that was not weeded at all. Weeding started on mid-June 2017/2018.

Sampling Methods

Weed assessment. Weed presence was determined using total weed counts, competitive weed counts above the crop canopy, and weed biomass. Weed percent cover of plots at the time of tarp removal was determined using a beaded string method (Shelton and Jasa, 2009) in which presence/absence of weeds under 30 beads along two cross-plot strings (5 m each) was recorded and converted to percentage. In 2017, the no-till with no cultivation treatment was not planted due to high weed pressure, but retained to assess weed density and weed biomass at the time of crop harvest without any soil disturbance. In 2018, the no-till was cultivated and planted with beets.

Weed biomass was taken prior to harvest both years, and 10 days after planting in 2018. Four 0.25 m^2 quadrats were placed on the soil surface in-row in the center four rows of each plot, and all weed biomass was clipped at the soil surface. Biomass was dried at 60°C for several days and reported as g/m2 weed biomass. Weed counts of species taller than the beet crop canopy (deemed competitive with the crop) - were taken in the middle four rows prior to harvest for both plantings. Total weed counts by species were taken 10 days after planting in 2018 using the same four 0.25 m^2 quadrats per plot used for 10-day weed biomass. Weed counts were used to calculate seed density per m^2.

Yield assessment. Beet stand counts were taken 10 days after planting both years. In 2018, beets were recounted and thinned to 15 beets per 30.5 cm at 24 days after planting. At the time of crop harvest, 3.7 meters of beets were taken (combined) from the four inner rows of each plot and sorted into size classes by plot. Size classes were measured by the diameter of the beetroot: <1.9 cm (Class 0), >1.9 to <3.8 cm(Class 1), >3.8 to <7.6 cm (Class 2), and >7.6 cm (Class 3). For analysis, classes 1, 2, and 3 were combined to assess marketable yield. Beets were counted and weighed both with and without greens within their size class to measure yield and stand counts.

Precipitation. Daily rainfall and temperature data were collected and summarized from weather stations at each site – the local NEWA station in Freeville, NY and Riverhead, NY (Network for Environment and Weather Applications, 2018), and an on-farm station in Monmouth, ME (HOBO U30, Onset Computer Corporation, Bourne, MA).

Statistical Analysis. All data were analyzed as a randomized complete block design. Least-squares means were compared using analysis of variance (ANOVA) in RStudio with tarp duration and tillage as fixed effects (RStudio, Inc., Boston, MA, U.S.). Mean separation was by the Tukey-Kramer HSD test at 0.05 level of probability. Prior to running the regression, data were checked for normality of residuals. For select weed biomass data, log transformation were applied prior to analysis to improve normality of residuals. Data for sites and planting dates were analyzed separately.

Results

Early-Season Weeds

Treatments with a tarp of three weeks or longer decreased weed percent cover by 95-100% in all site years at the time of removal (Table A3-A5).

Ten days after tarp removal, tarped treatments had lower weed density than bare-ground treatments in Riverhead ($p<0.001$), with a density of 71 weeds·m^{-2} in no-tarp treatments and <2 weeds·m^{-2} in tarped treatments (Table A5). There was no difference in weed density between treatments in Freeville (Table A3). Tillage significantly decreased ten-day weed density in all site years ($p<0.001$) (Table A3-A5). Ten-day weed density data were only collected in 2018, and were not collected in Monmouth.

Weed biomass collected ten days post-tarp removal was significantly lower in tarped plots compared with bare-soil plots in Riverhead ($p<0.01$), and in planting two in Monmouth ($p<0.001$) and Freeville ($p<0.001$) (Table A3-A5). There was no difference in ten-day weed biomass between tarp treatments in planting one in Freeville or Monmouth. Tillage significantly decreased ten-day weed biomass in Freeville and Riverhead ($p<0.05$), but not in Monmouth. Ten-day weed biomass was only collected in 2018.

Late-Season Weeds

Tarp use significantly decreased weed biomass prior to crop harvest in all site years in Monmouth ($p<0.01$) (Table 2). In Freeville, tarps decreased weed biomass in planting two both years ($p<0.05$), but not in planting one. In Riverhead, tarp use decreased weed biomass in 2017 ($p<0.01$) but not in 2018.

There was a significant interaction between tarp and tillage treatments for pre-harvest weed biomass in seven out of ten site years (Table 2). In treatments with no tarp, tillage significantly reduced weed biomass up to nine times in conventionally tilled plots compared with no-till plots. In treatments with tarp use of any duration, however, there was no significant difference between tillage treatments except in Monmouth planting two in 2018 (Table 2).

Beet Yield

There were generally more beets of size class one (>1.9 to <3.8 cm diameter) and two (>3.8 to <7.6 cm diameter) in tarped plots than untarped plots across tillage treatments in all site years (Figure A8-A9). Tarp use did not seem to affect the proportion of beets over 7.6 cm in diameter. Number of small, unmarketable beets (<1.9 cm diameter) fluctuated more with tillage than with tarp treatment, with more small beets in no-till treatments than reduced or conventional-till treatments (except in no-till, no-tarp treaments in Monmouth, when there were no beets at all).

Tarp use significantly increased total marketable beet yield (size classes 1-3, roots and tops included). The average yield increase across plantings and years for Freeville, Monmouth, and Riverhead was 61%, 60%, and 54% respectively between no-tarp and tarp treatments (Table A6-A8). The highest percent increase in yield was 89% in Monmouth planting two between no-tarp and long duration tarp treatments. The lowest increase was 17% in Freeville planting one between no-tarp and mid duration tarp treatments.

Overall, tillage only increased beet yield in four out of ten site years. There was, however, a significant interaction between tarp and tillage treatments in five out of ten site years (Table 3) for marketable beet yield. A similar trend showed across all sites and years, but was not always significant to $p<0.05$. Tillage significantly increased marketable yield in no-tarp treatments, but yield was similar across tillage treatments in tarped treatments (Table 3). For example, in Freeville 2018 planting two, there was a significant interaction between tarp and tillage treatments ($p<0.01$). Under no-tarp management, conventional tillage increased beet yield 83% compared with reduced-till and no-till. In tarp treatments of any duration, there was no significant difference in yield between conventional-, reduced-, or no-till treatments. Tarp duration did not influence beet yield.

Discussion

Early-Season Weeds

Tarp use of three weeks was sufficient time to kill any emerged weeds present at the time of tarp application. This is consistent with data in New Hampshire and Maine (Birthisel, 2018; Lounsbury et al., 2018), as well as farmer observations. Tarps create a surface free of weeds in which to plant, giving crops a head start early in the season. Delaying weed emergence early in the season gives crop seeds or transplants a temporal competitive advantage over weeds during a critical period of growth (Chaudhari et al., 2016; Safdar et al., 2016).

Weed pressure ten days post tarp removal varied by planting and site. Tarps had a lasting effect on both weed density and biomass in Riverhead, while in Freeville and Monmouth tarps only decreased ten-day weed presence for the later planting dates. Riverhead had only one planting date, but the climate at the Riverhead site is warmer than at the Freeville or Monmouth sites (Figure A1-A3). This suggests that tarps may be more effective at suppressing weeds in warmer parts of the season.

The mechanisms behind this are unclear. Tarps do not consistantly increase soil temperatures until later in the season (Rylander, 2019), so the cooler soils present in early-planting tarp durations may not be conducive to weed seed germination. Most summer annuals germinate in May or June, depending upon the climate, which was the time of tarp removal for planting one in Freeville and Monmouth. No weeds had germinated at the time of tarp application for any treatment in planting one, and cool temperatures may have delayed germination until after tarp removal. For planting two, short duration tarps were laid over mature weeds, killing any already emerged weeds. Temperatures were also warmer during the later weeks of tarping for planting two, which may have increased fatal germination under tarps in other treatments.

Increased nitrate concentrations under tarps may increase germination of weed seeds. Weed seeds are often smaller than crop seeds, lacking significant reserves to grow on in the event of germination. This makes them more plastic to increases in soil nutrients, such as nitrate, potentially breaking dormancy due to nitrate availability. Tarps do not, however, increase the germination or degradation of *C. album* or *A. powellii* seeds (Rylander, 2019). Other weed species may increase in germination under tarps.

There was no advantage to longer tarp duration for early season weed suppression. Three weeks was sufficient time to create a planting bed free of weeds and reduce competition for ten days. This provides farmers with greater flexibility in cropping plans by limiting the amount of time a tarp must remain on the ground to effectively suppress weeds.

Late-Season Weeds

The effect of tarps on weed pressure varied by location. Similar to ten-day weed density and biomass, tarps only decreased weed biomass at harvest in later planting dates in Freeville. Tarps in Monmouth decreased weed biomass at harvest for both planting dates. Specific tarp-weed interaction may vary by region and farm, depending upon climactic conditions and weed species populations.

Reduced-till and no-till treatments paired with tarp use of any duration had comparable end-of-season weed control to conventionally tilled plots with no tarp. Tarp effect on weeds was not as prominent at the end of the growing season compared with at the time of tarp removal or ten days post-tarp removal. In New Hampshire, tarps decrease weed biomass at harvest, but have a significant interaction with roller-crimper date (Lounsbury et al., 2018). Longevity of weed suppression by tarps likely depends upon a number of factors, such as tillage method and presence of crop residue.

There was little perennial pressure at the three sites, but farmer communication suggests that tarps may deplete perennial reserves and eventually kill perennial weeds, though more than three weeks is likely needed for permanent suppression. Red clover was effectively controlled by tarps in Monmouth.

Beet Yield

Tarps increased crop yield in reduced-till and no-till treatments, resulting in yields comparable to that in conventional-till treatments. Tarps increased the number of beets in size classes one and two. As these sizes (3.8-7.6 cm diameter) constituted the bulk of marketable beets in the experiment, tarps increased the number of marketable beets per plot. Beet yield increase was likely the result of decreased weed pressure by tarps. Yield was likely also affected by nutrient concentrations in the soil. Tarps increase nitrate concentrations in the soil by up to 21 times that of uncovered soil (Rylander, 2019). Increased availability of nitrate at the start of the growing season could increase crop growth, resulting in higher yields.

Similarly, tarps increase cabbage yield by 58% in a roller-crimper reduced till system (Lounsbury et al., 2018). In this roller-crimper system, however, tarps degraded crop residue by over 1100 $kg \cdot ha^{-1}$ compared with bare ground and clear tarp treatments. For our experiment, tarps did not degrade crop residue, and preserved it in some site years. Despite direct-seeding into crop and weed residue, beet yields did not decrease from reduced-till management. The weed control and nutrient availability provided by tarps made yield comparable between tillage treatments. The interaction between tarp use and tillage treatment for yield indicates that tarps could make reduced-till and no-till more viable in organic vegetable systems.

Conclusions

Tarp use of three or more weeks significantly reduced weed percent cover at the time of tarp removal, and retained lower weed pressure ten days after tarp removal, creating a weed-free planting bed in the critical first few weeks of crop growth.

Despite high crop residue cover in no till and reduced till treatments, beet yield increased in all tarped treatments compared with untarped treatments, likely due to increased weed suppression and nitrate availability.

Tarp use decreased the difference in both late-season weed biomass and crop yield between tillage treatments. Beet yields in no-till and reduced-till tarped treatments were similar to yields in conventional till treatments, indicating that tarp use may make reduced tillage more viable in organic vegetable systems.

Increasing tarp duration longer than three weeks did not have a significant effect on weed suppression or beet yield at any point in the season. Farmers therefore retain more flexibility in their farm management plans by using tarps for shorter periods of time. Using tarps prior to planting a cash crop can help control early-season weeds and reduce the number of tillage passes a farmer needs prior to planting.

Further research on tillage prior to tarping and the response of different crop and weed species to tarping would increase the understanding of tarp impacts on crop yield and reducing tillage.

Table 1. Experiment dates for Freeville, NY, Monmouth, ME, and Riverhead, NY for two planting dates (P1 and P2) in two years: 2017, 2018.

	Freeville				Monmouth				Riverhead	
	2017		2018		2017		2018		2017	2018
	P1	P2	P1	P2	P1	P2	P1	P2		
Cover Crop Planted	25 Aug.	25 Aug.	25 Aug.	25 Aug.	Mid Aug.	Mid Aug.	Mid Aug.	Mid Aug.	9 Sept.	26 Sept.
Long duration tarp	15 Nov.	30 Mar.	17 Nov.	2 Apr.	8 Dec.	27 Apr.	21 Nov.	10 Apr.	19 Jan.	21 Nov.
Mid duration tarp	30 Mar.	26 Apr.	2 Apr.	30 Apr.	13 Apr.	17 May	13 Apr.	21 May	11 Apr.	13 Apr.
Short duration tarp	20 Apr.	18 May	23 Apr.	21 May	3 May	9 June	15 May	11 June	2 May	4 May
Tarps removed	16 May	16 June	14 May	11 June	8 June	6 July	5 June	11 July	1 June	29 May
Tillage applied	23 May	22 June	17-18 May	12-14 June	8 June	6 July	5 June	11 July	2 June	30 May
Beets planted	23 May	22 June	18 May	15 June	8-12 June	6 July	5 June	14 July	2 June	30 May
Beets harvested	25 July	15 Aug.	18 July	13 Aug.	9 Aug.	20-26 Sep.	8 Aug.	11 Sep.	1-3 Aug.	30 July – 1 Aug.

Table 2. Effect of tillage and tarp duration on pre-harvest weed biomass ($g \cdot m^{-2}$) for Plantings 1 (P1) and 2 (P2) in 2017 and 2018 at Freeville, NY, Monmouth, ME, and Riverhead, NY. Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm).

		Freeville, NY[w]				Monmouth, ME[x]				Riverhead, NY[y]	
		2017		2018		2017		2018		2017	2018
Tarp	Tillage	P1	P2	P1	P2	P1	P2	P1	P2		
None	None	--	--	144	281 a	740 a	864 a	519 b	666 b	571 a	276 a
	Reduced	121[y]	409 a[z]	134	253 a	243 b	331 b	95 a	310 a	260 b	136 b
	Conv.	88	103 b	97	72 b	82 c	249 b	92 a	328 a	--	--
	p-value	NS	***	NS	*	*	***	***	**	***	**
Short	None	--	--	95	84	113	330	69	168	215	163
	Reduced	55	39	148	136	104	227	123	165	347	153
	Conv.	79	34	86	206	132	183	54	138	--	--
	p-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mid	None	--	--	119	149	59	62	108	79	181	193
	Reduced	62	37	117	183	85	122	138	101	219	170
	Conv.	85	44	58	178	86	142	152	136	--	--
	p-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Long	None	--	--	92	218	110	75	73	101 b	344	158
	Reduced	80	26	132	223	181	209	104	374 a	289	160
	Conv.	95	46	87	262	132	61	121	260 ab	--	--
	p-value	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
	Tarp (Tr)	NS	NS	***	NS	***	***	***	***	**	NS
	Till (Tl)	NS	NS	*	**	***	**	***	NS	NS	NS
	Tr x Tl	NS	NS	***	NS	***	***	***	***	***	NS

[w]Data taken mid-May for Planting 1 and mid-June for Planting 2 both years
[x]Data taken mid-June for Planting 1 and mid-July for Planting 2 both years
[y]Data taken early June in 2017 and Late may in 2018 (only one planting date)
[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 3. Effect of tillage and tarp duration on fresh beet weight (roots and tops) in $g \cdot m^{-2}$ for Plantings 1 (P1) and 2 (P2) in 2017 and 2018 at Freeville, NY, Monmouth, ME, and Riverhead, NY. Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm).

		Freeville, NY[w]				Monmouth, ME[x]				Riverhead, NY[y]	
		2017		2018		2017		2018		2017	2018
Tarp	Tillage	P1	P2	P1	P2	P1	P2	P1	P2		
None	None	--	--	36 a	332 b	0	0 a	0 a	0	0	128
	Reduced	2579	0 b[z]	586 a	308 b	748	3053 b	1193 ab	90	542	1131
	Conv.	3681	1685 a	2293 b	1926 a	1614	3976 b	2433 b	283	--	--
	p-value	NS	**	***	***	NS	*	***	NS	NS	NS
Short	None	--	--	1399 a	2042	2600	4831	1560	784	281	709
	Reduced	3902	3009	1791 ab	2206	2191	5698	2277	587	612	962
	Conv.	3921	3338	2267 b	1909	2165	5824	2543	719	--	--
	p-value	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Mid	None	--	--	1388 a	1616	2201	4460	1261	1046	615	835
	Reduced	3687	2658	1776 ab	1941	2271	4952	1546	1031	963	1484
	Conv.	3848	2673	2347 b	1707	2687	4295	2098	1308	--	--
	p-value	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Long	None	--	--	2215 a	1054	2952	7610	1751	642	674	1260
	Reduced	4705	3440	1973 a	1869	3102	6817	1887	765	1094	1690
	Conv.	4654	3188	3002 b	1446	3200	6053	2490	842	--	--
	p-value	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
	Tarp (Tr)	**	***	***	***	***	***	*	***	*NS*	*NS*
	Till (Tl)	*NS*	*NS*	***	*	*NS*	*NS*	***	*NS*	*NS*	*NS*
	Tr x Tl	*NS*	*	*	**	*NS*	*	*NS*	*NS*	*NS*	*NS*

[w]Data taken mid-May for Planting 1 and mid-June for Planting 2 both years
[x]Data taken mid-June for Planting 1 and mid-July for Planting 2 both years
[y]Data taken early June in 2017 and Late may in 2018 (only one planting date)
[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05, 0.01, 0.001$ respectively.

Works Cited

Abu-Gharbieh, W.I., H. Saleh, and H. Abu-Blan. 1988. Use of black plastic for soil solarization and post-plant mulching. Plant Protection Dept., Faculty of Ag., Univ. of Jordan, Amman, Jordan.

Altieri, M.A., M.A. Lana, H.V. Bittencourt, A.S. Kieling, J.J. Comin, and P.E. Lovato. 2011. Enhancing crop productivity via weed suppression in organic no-till cropping systems in Santa Catarina, Brazil. J. Sustainable Ag. 35(8):855–69.

Arshad, M.A., A.J. Franzluebbers, and R.H. Azooz. 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil Tillage Res. 53:41-47.

Beare, M.H., S. Hu, D.C. Coleman, and P.F. Hendrix. 1997. Influences of mycelial fungi on soil aggregation and organic matter storage in conventional and no-tillage soils. Appl. Soil Ecol. 5(3):211–19.

Birthisel, S.K.. 2018. Multi-tactic ecological weed management in a changing climate. Univ. of Maine, Orono, PhD Diss. 2928.

Buhler, D.D., D.E. Stoltenberg, and R.L. Becker. 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. Weed Sci. 42:205-209.

Campiglia, E., E. Radicetti, and R. Mancinelli. 2018. Floristic composition and species diversity of weed community after 10 years of different cropping systems and soil tillage in a Mediterranean environment. Weed Res. 58:273-283.

Canali, S., G. Campanelli, C. Ciaccia, F. Leteo, E. Testani, and F. Montemurro. 2013. Conservation tillage strategy based on the roller crimper technology for weed control in Mediterranean vegetable organic cropping systems. European J. Agron. 50:11–18.

Candido, V., D. Castronuovo, V. Miccolis, and T. D'Addabbo. 2011. Weed control and yield response of soil solarization with different plastic films in lettuce. Scientia Horticulturae 130:491-497.

Cavalaris, C.K. and T.A. Gemtos. 2002. Evaluation of four conservation tillage methods in the sugar beet crop. CIGR J. Sci. Res. Dev. 4.

Chaudhari, S., S.J. McGowen, F.J. Louws, K.M. Jennings, D.W. Monks, D.L. Jordan, and C.C. Gunter. 2016. Critical period for weed control in grafted and nongrafted fresh market tomato. Weed Sci. 64:523-530.

Chauhan, B.S., G.S. Gill, and C. Preston. 2006. Tillage system effects on weed ecology, herbicide activity and persistence: A review. Australian J. Expt. Ag. 46:1557-1570.

Ciaccia, C., S. Canali, G. Campanelli, E. Testani, F. Montemurro, F. Leteo, and K. Delate. 2016. Effect of roller-crimper technology on weed management in organic zucchini production in a Mediterranean climate zone. Renewable Ag. Food Systems 31(2):111–21.

Clements, D.R., D.L. Benott, S.D. Murphy, D.L. Benoit, and C.J. Swanton. 1996. Rillage effects on weed seed return and seedbank composition. Weed Sci. 44(2):314-322.

Egley, G.H.. 1983. Weed seed and seedling reductions by soil solarization with transparent polyethylene." Weed Sci. 31.

Franzluebbers, A.J.. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Tillage Res. 66:197-205.

Gupta, V.V.S.R. and J.J. Germida. 1988. Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. *Soil Biol. and Biochem.* 20(6):777–86.

Halde, C., K.C. Bamford, and M.H. Entz. 2015. crop agronomic performance under a six-year continuous organic no-till system and other tilled and conventionally-managed systems in the Northern Great Plains of Canada. Ag. Ecosystems Environ. 213:121–30.

Hungria, M., J.C. Franchini, O. Brandão-Junior, G. Kaschuk, and R.A. Souza. 2009. Soil microbial activity and crop sustainability in a long-term experiment with three soil-tillage and two crop-rotation systems. Appl. Soil Ecol. 42(3):288–96.

Johnson, M.D. and B. Lowery. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Soil Sci. Soc. Amer. J. 49:1547–52.

Jokela, D. and A. Nair. 2016. effects of reduced tillage and fertilizer application method on plant growth, yield, and soil health in organic bell pepper production. Soil Tillage Res. 163:243-254.

Kanaan, H., S. Frenk, M. Raviv, S. Medina, and D. Minz. 2018. Long and short term effects of solarization on soil microbiome and agricultural production. Appl. Soil Ecol. 124:54-61.

Kasirajan, S. and M. Ngouajio. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agron. for Sustainable Dev. 32:501-529.

Khan, M.A., R. Khan, H. Khan, H.U. Shah, K.B. Marwat, A. Amin, and A. Nawaz. 2012. Soil solarization: An organic weed-management approach in cauliflower. Commun. Soil Sci. Plant Analysis 43(13):1847–60.

Koch, H-J., B. Märländer, A. Büchse, and J. Dieckmann. 2009. Yield decrease in sugar beet caused by reduced tillage and direct drilling. European J. Agron. 30(2):101–9.

Laufer, D., B. Loibl, B. Märländer, and H-J. Koch. 2016. Soil erosion and surface runoff under strip tillage for sugar beet (*Beta vulgaris L.)* in central Europe." Soil Tillage Res. 162:1-7.

Leavitt, M.J., C.C. Sheaffer, D.L. Wyse, and D.L. Allan. 2011. rolled winter rye and hairy vetch cover crops lower weed density but reduce vegetable yields in no-tillage organic production. HortScience 46(3):387-395.

Linke, K.H.. 1994. Effects of Soil Solarization on Arable Weeds under Mediterranean Conditions: Control, Lack of Response or Stimulation. Crop Protection 13(2):115-120.

Marinello, F., A. Pezzuolo, D. Cillis, A. Chiumenti, and L. Sartori. 2017. Traffic effects on soil compaction and sugar beet (*Beta vulgaris L.*) taproot quality parameters. Spanish J. Ag. Res. 15(1).

Nakamoto, T., J. Yamagishi, and F. Miura. 2006. Effect of reduced tillage on weeds and soil organisms in winter wheat and summer maize cropping on humic andosols in central Japan. Soil and Tillage Res. 85(1-2):94–106.

Mendoza, R.B., T.G. Franti, J.W. Doran, T.O. Powers, and C.W. Zanner. 2008. Tillage effects on soil quality indicators and nematode abundance in loessial soil under long-term no-till production. Commun. Soil Sci. Plant Analysis 39:2169-2190.

Power, J.F., W.W. Wilhelm, and J.W. Doran. 1986. Crop residue effects on soil environment and dryland maize and soya bean production. Soil Tillage Res. 8:101–11.

Rylander, H.R.. 2019. Black plastic tarp impact on soil measures, weed seeds, and crop residue. Cornell Univ., Ithaca, Masters Thesis.

Safdar, M.E., A.Tanveer, A. Khaliq, and R. Maqbool. 2016. Critical competition period of parthenium weed (*Parthenium hysterophorus* L.) in maize. Crop Protection 80:101-107.

Samtani, J.B., J. Derr, M.A. Conway, and R.D. Flanagan III. 2017. Evaluating soil solarization for weed control and strawberry (*Fragaria xananassa*) yield in

Sharifi, M., C.F. Drury, B.G. McConkey, N. Ziadi, S. Bittman, B.J. Zebarth, D.L. Burton, and C.A. Grant. 2008. Response of potentially mineralizable soil nitrogen and indices of nitrogen availability to tillage system. Soil Sci. Soc. Amer. J. 72(4):1124–31.

Shelton, D.P. and P.J. Jasa. 2009. Estimating percent residue cover using the line-transect method. NebGuide. University of Nebraska, Lincoln. <http://extensionpublications.unl.edu/assets/pdf/g1931.pdf>

Öz, H.. 2018. A new approach to soil solarization: Addition of biochar to the effect of soil temperature and quality and yield parameters of lettuce (*Lactuca sativa L. Duna*). Scientia Horticulturae 228:153–61.

Tebrügge, F. and R.-A. Düring. 1999. Reducing tillage intensity: A review of results from a long-term study in Germany. Soil Tillage Res. 53:15–28.

Van den Putte, A., G. Govers, J. Diels, K. Gillijns, and M. Demuzere. 2010. Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. European J. Agron. 33:231-241.

Wilhelm, W., J.W. Doran, and J.F. Power. 1986. Corn and soybean yield response to crop residue management under no-tillage production systems. Agron. J. 78:184-189.

Yapa, L.G.G., D.D. Fritton, and S.T. Willatt. 1988. Effect of soil strength on root growth under different water conditions. Plant Soil 109:9-16.

FINAL SUMMARY

Black plastic tarps affect the soil environment, weed suppression, and crop yield in reduced tillage systems for beets. Tarps increase soil moisture in dry conditions and have less soil moisture fluctuation than uncovered soil throughout their duration. Preserving soil moisture is important for farmers in the face of climate change, with droughts becoming increasingly more common. Crops seeded or transplanted into moist soil have a better chance of success. Tarps are a low-cost tool to improve water management on small farms.

The effect of tarps on soil temperature throughout their duration is not clear. There was no discernable pattern between treatments, and tarps likely do not have a strong effect on soil temperature in the cooler months of winter and early spring. By May, however, tarps did increase soil temperatures 1-3°C compared with uncovered soil, sometimes increasing temperatures by up to 10°C in warmer conditions. Increased soil temperatures are beneficial to seed germination, allowing for earlier planting of crops and possibly encouraging fatal weed seed germination. Increased temperatures also benefit microbial activity, improving nutrient contents in the soil by promoting nitrification and other mineralization.

Soil nitrate increased significantly with tarp use, and linearly with tarp duration. Correlation between nitrate, moisture, and temperature indicates that tarps likely increase nitrate in the soil by providing more moist, warm conditions than bare soil, thereby promoting microbial activity and nitrification. Tarps likely decrease leaching of nitrate throughout the winter and spring, at a time when crops are not in the ground to take up nitrate. Nitrate is one of the most important nutrients for crops, and increased concentrations at the time of planting decrease farmer reliance on fertilizers and amendments, lowering cost and increasing crop growth.

Tarps create a moist, warm, nitrate-rich environment in which to plant. Using tarps for three or more weeks prior to planting can help improve soil health and planting conditions, reducing farmer reliance on irrigation and nitrogen fertilization, and possibly allowing for earlier planting. Tarps did not, however, decrease crop residue, which may be problematic for reduced-till planting and management. Other studies and farmer observations report increased crop residue degradation under tarps. Tarp effect on crop residue may depend on the cover crop species and environmental conditions at the time of tarp use.

The primary way in which tarps facilitate reduced tillage is by weed control. The interaction with tarps and weeds is complex, and not fully explained by this research. Tarps had no effect on *C. album* seed germination or degradation, and actually increased *A. powellii* survivability, indicating that neither seed germination nor degradation were increased by tarp use for these species. Observed white thread seedlings under early tarp treatments by researchers and by farmers, however, suggests that some weed species do germinate under tarps. For certain species, tarps may be used to create a stale seedbed by promoting fatal germination of weed seeds.

Whatever the mechanism of weed suppression, tarps effectively killed all living weeds within three weeks. This alone allows tarps to reduce tillage by eliminating the need for multiple passes prior to planting for weed control. A farmer transplanting a crop may eliminate all tillage prior to planting, transplanting directly into weed-free crop residue. A farmer with compacted soil or direct seeding may till once before or after tarping to create a smooth soil surface for planting, and use tarps to preserve the planting bed and keep weeds from germinating and living.

Tarps may have a lasting effect on weed suppression, though results varied by site year. Ten days post tarp removal, weed density and biomass were often lower in tarped plots. By harvest time, tarps alone decreased weed biomass in only some site years, but also decreased the difference between tillage treatments. The same interaction affected beet yield. In untarped plots, conventional tillage significantly decreased weed biomass and increased beet yield compared with reduced-till and no-till. In tarped plots of any duration, there was no difference in weed biomass or beet yield between conventional-, reduced-, and no-till treatments. Despite high crop residue, beet yield increased in tarped plots compared with untarped plots. This yield increase was likely due to increased weed suppression and nitrate availability.

Tarps do have limitations. Tarps are large and heavy, and physical handling and storage can prove difficult for small-scale farmers. Farmers must be prepared to manage the pooling of water on tarps and divert runoff into appropriate areas of their fields in rain events. Incorporating tarps into crop plans can take time and effort, potentially increasing the length of time between crop rotations and consuming beds during parts of the planting season.

Despite limiations, tarps are a viable option for reducing tillage in organic vegetable systems. Farmers can get comparable weed suppression and crop yields in reduced-till systems as in conventional-till systems when using tarps for just three weeks prior to planting. There was no benefit to using tarps beyond three weeks, except increased nitrate concentrations. This allows greater flexibility in farm management plans.

APENDIX

Table A1**.** Inorganic nitrogen concentrations (ppm) in N-NO3 and N-NH4 in the top 15 cm of soil post-tarp removal for Freeville, NY, Monmouth, ME, and Riverhead, NY separated by planting date (P1 and P2) and year.

		2017				2018			
		P1[v]		P2[w]		P1[x]		P2[y]	
Location	Tarp time	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
Freeville	None	2 a[z]	7	2.9 c	7	2 c	14	2 b	15
	Short	8 a	5	18 b	6	7 b	12	14 a	17
	Mid	8 a	6	25 ab	5	10 b	14	15 a	15
	Long	28 b	6	31 a	6	22 a	12	17 a	14
		***	NS	***	NS	***	NS	***	NS
Monmouth	None	10	3	2 c	11 b	2 a	4	2 a	4
	Short	16	3	20 b	8 a	16 b	3	37 b	4
	Mid	22	3	29 ab	6 a	22 b	3	42 b	4
	Long	18	3	36 a	8 a	24 b	4	42 b	4
		NS	NS	***	**	***	NS	***	NS
Riverhead	None	1.3 c	9.4	--	--	1.0 a	8.1	--	--
	Short	6.8 ab	10.0	--	--	--	--	--	--
	Mid	10.4 b	10.3	--	--	5.8 b	8.2	--	--
	Long	11.6 a	9.2	--	--	--	--	--	--
		***	NS	--	--	***	NS	--	--

[v]Planting date for Freeville: 23 May 2017, Monmouth: 8-12 June 2017, Riverhead: 2 June 2017
[w]Planting date for Freeville: 22 June 2017, Monmouth: 6 July 2017; Riverhead had only one planting
[x]Planting date for Freeville: 18 May 2018, Monmouth: 5 June 2018, Riverhead: 30 May 2018
[y]Planting date for Freeville: 15 June 2018, Monmouth: 14 July, 2018, Riverhead had only one planting
[z]Mean separation by Tukey HSD at $P \leq 0.05$. Any two means within a column not followed by the same letters are significantly different.
[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

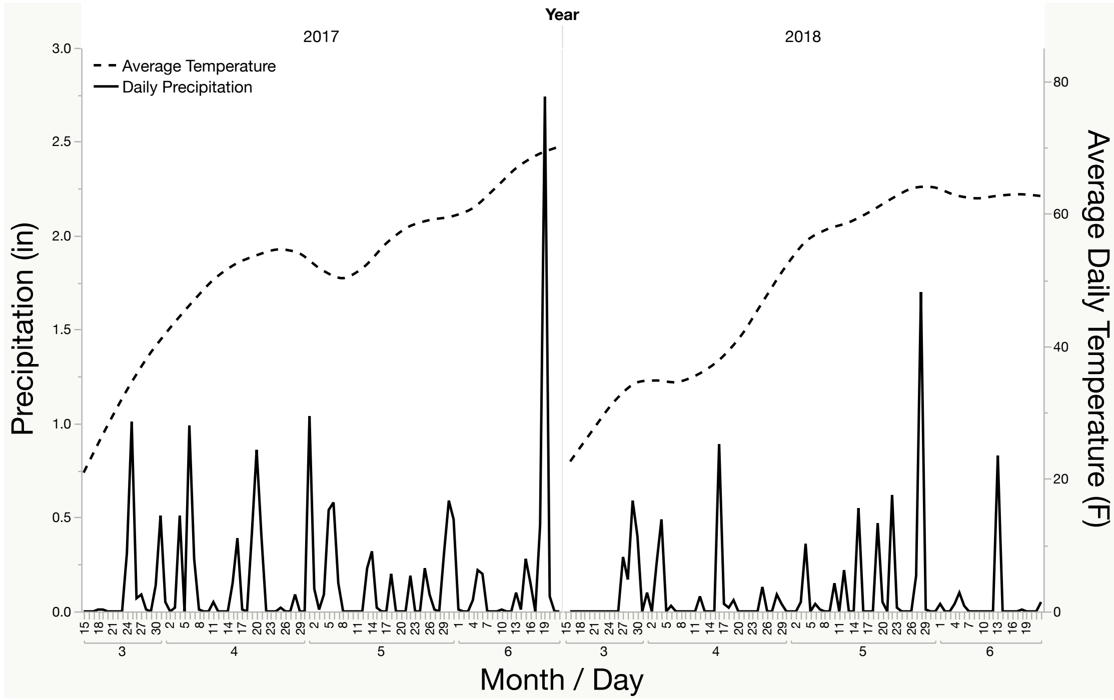


Figure A1**.** Daily precipitation (in.) and average daily temperature (F) in Freeville, NY from 3 March – 22 June 2017 and 15 March – 22 June 2018.

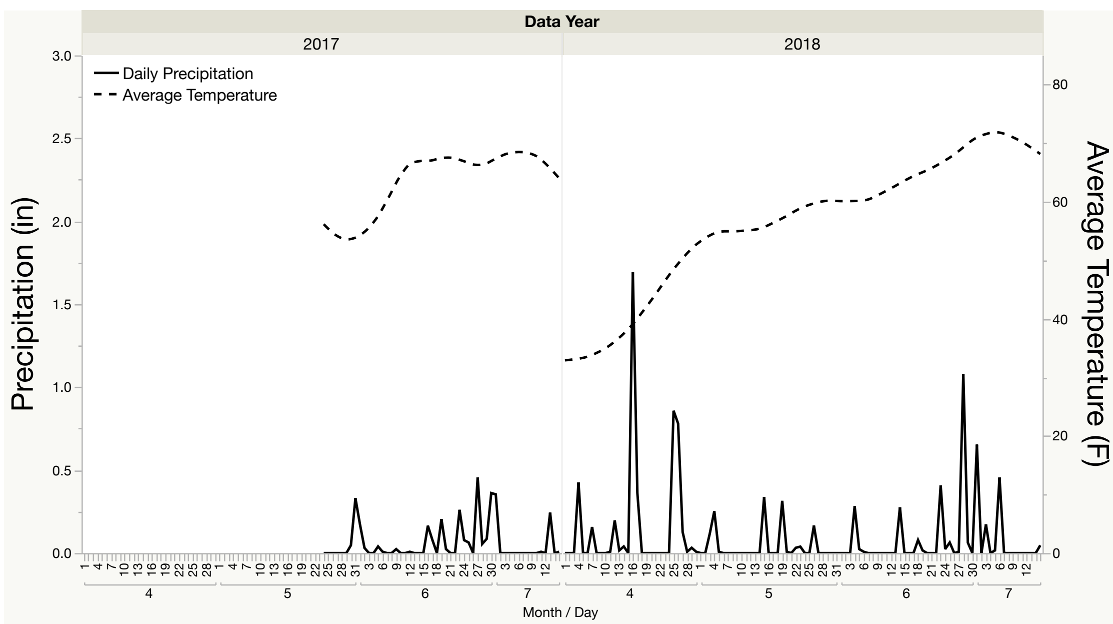


Figure A2**.** Daily precipitation (in.) and average daily temperature (F) in Monmouth from 24 May – 15 July 2017 and 1 Apr. – 15 June 2018.

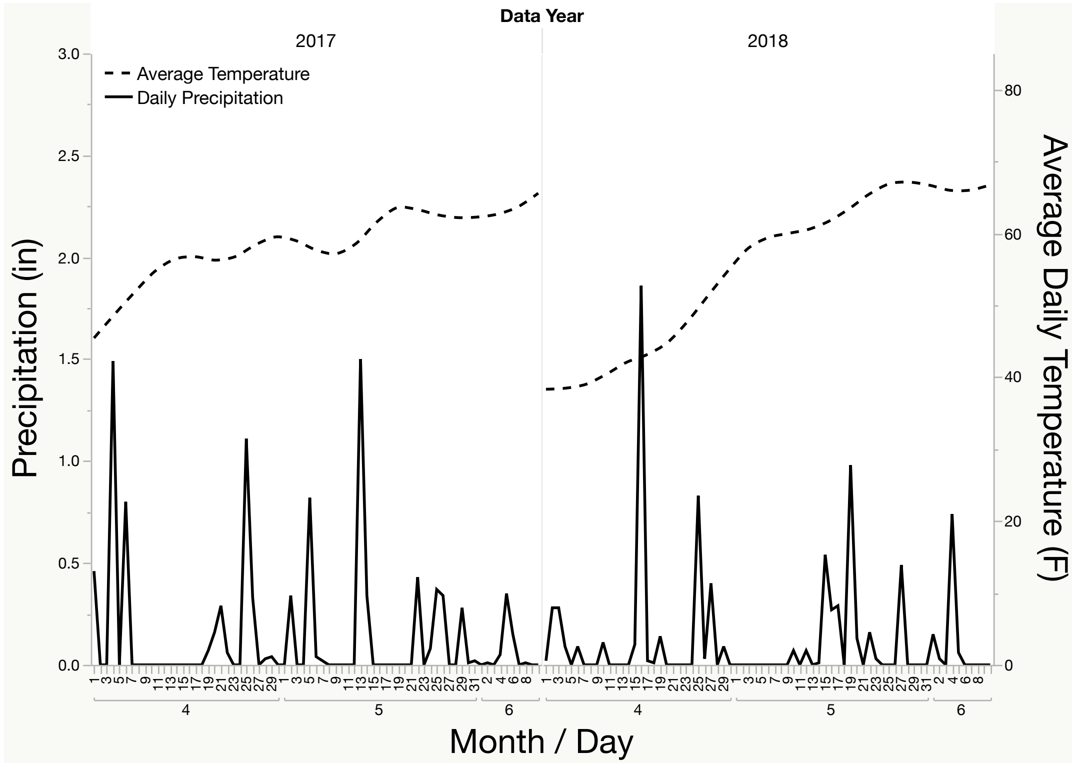


Figure A3**.** Daily precipitation (in.) and average daily temperature (F) in Riverhead, NY from 1 Apr. – 10 June 2017 and 2018.

Table A2**.** Weed seed survivability (%) as an indicator of tarp effect on germination and degradation rates using a crush method in Freeville, NY 2018 for two planting dates (P1 and P2).

	P1[v]		P2[w]	
Tarp Duration	AMAPO[x]	CHEAL[y]	AMAPO[x]	CHEAL[y]
None	0.73 a[z]	0.89	0.61 ab	0.82
Short	0.82 b	0.90	0.59 b	0.86
Long	--	--	0.70 a	0.85
	*	NS	*	NS

[v]Seed bags collected 14 May 2018
[w]Seed bags collected 11 June 2018
[x]*Amaranthus powellii* S. Wats
[y]*Chenopodium album* L.
[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

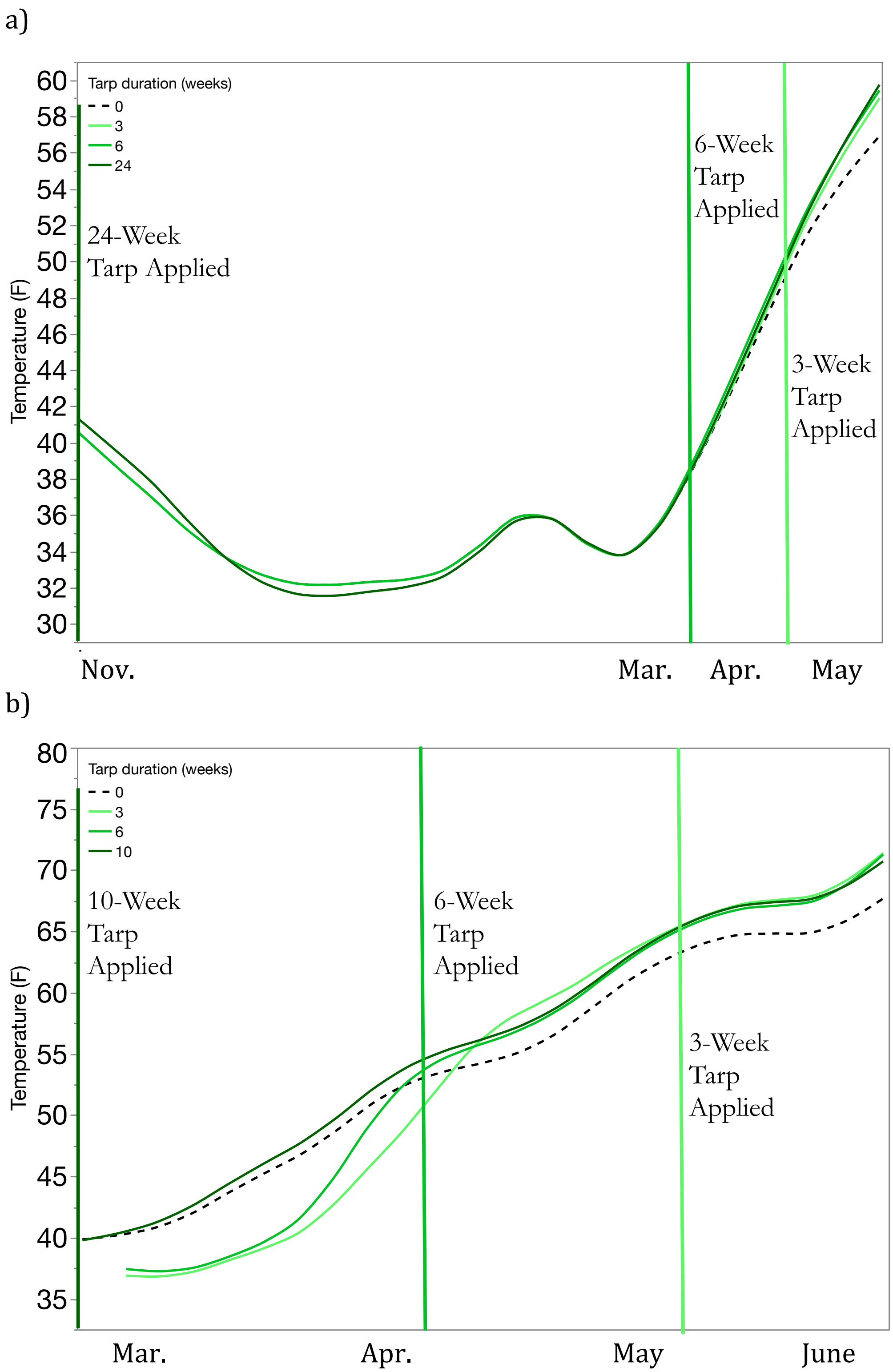


Figure A4**.** Soil temperature (F) at a 20 cm depth in Freeville, NY for a) Planting 1 and b) Planting 2 for 0, 3, 6, and 10+ week tarp treatments. Data are averaged across two years: 2017, 2018.

a)

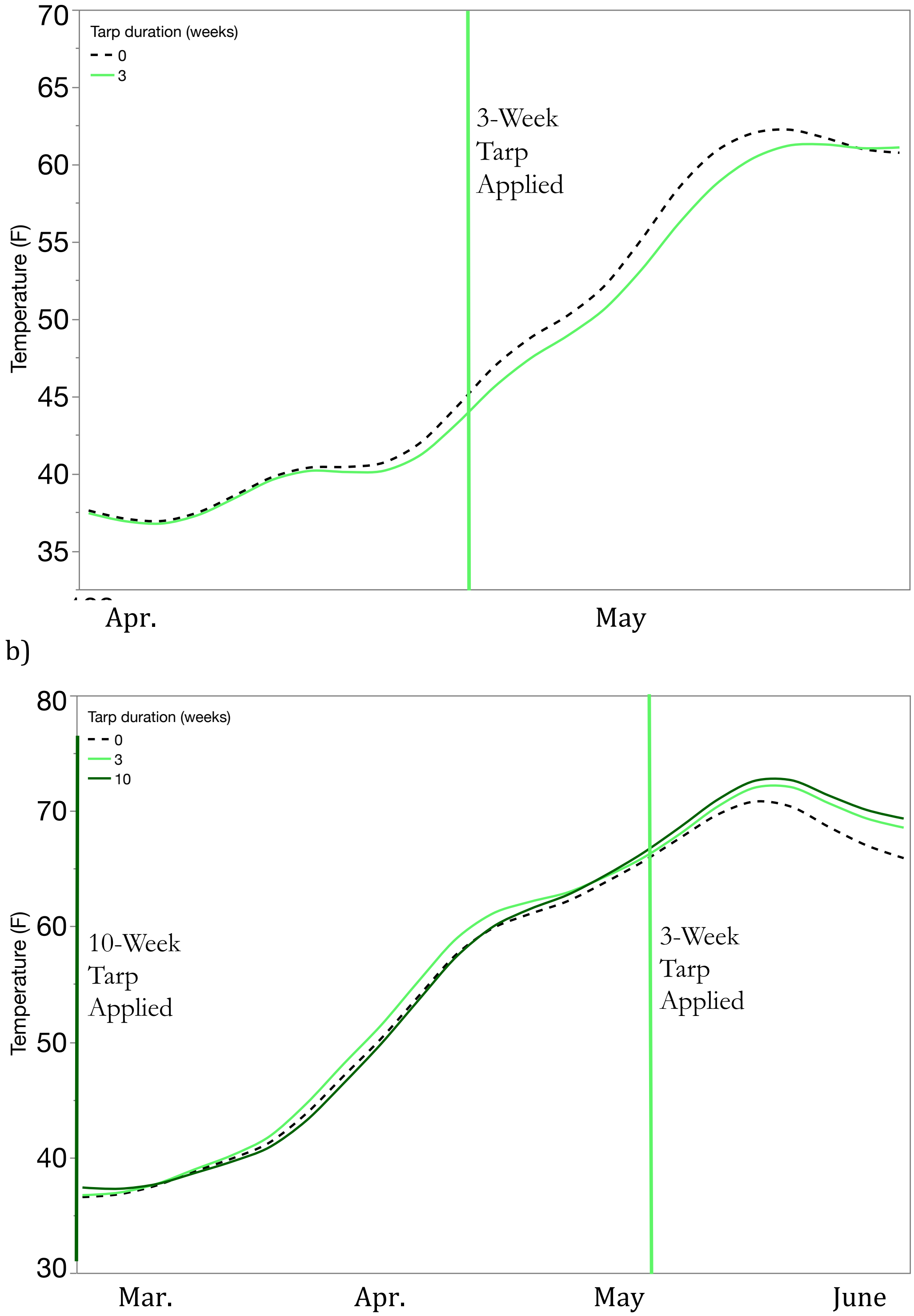


Figure A5. Soil temperature (F) at a 1 cm depth in Freeville, NY in 2018 for a) Planting 1 and b) Planting 2 for 0, 3, and 10+ week tarp treatments.

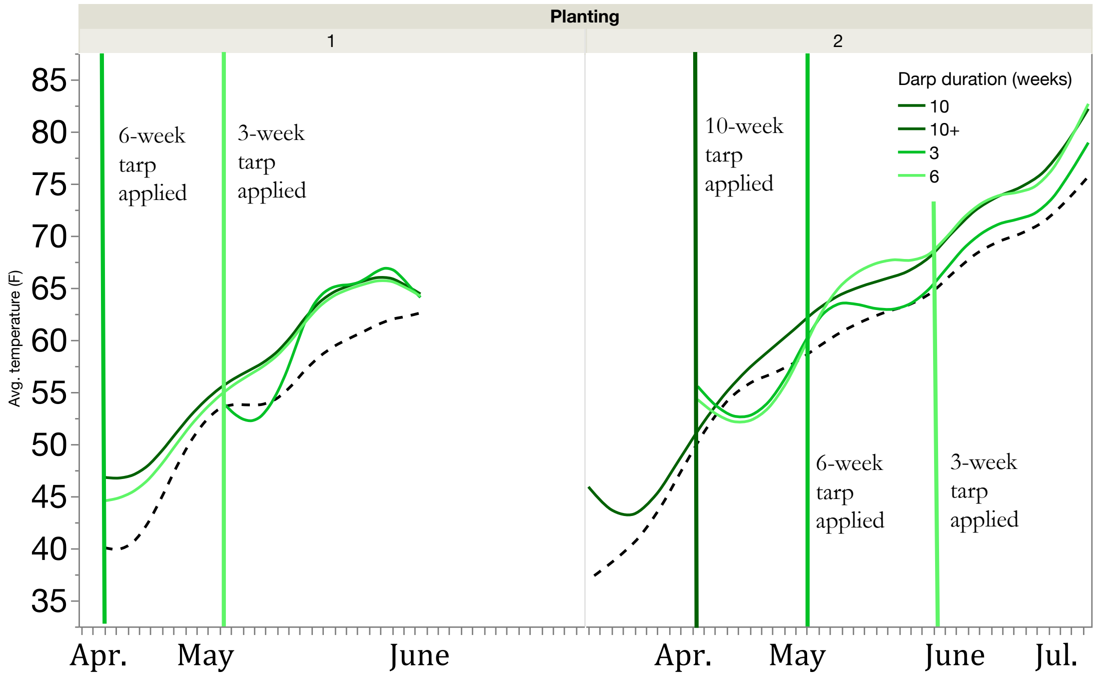


Figure A6. Soil temperature (F) at a 20 cm depth in Monmouth, ME for Planting 1 and Planting 2 for 0, 3, 6, and 10+ week tarp treatments. Data are averaged across two years: 2017, 2018.

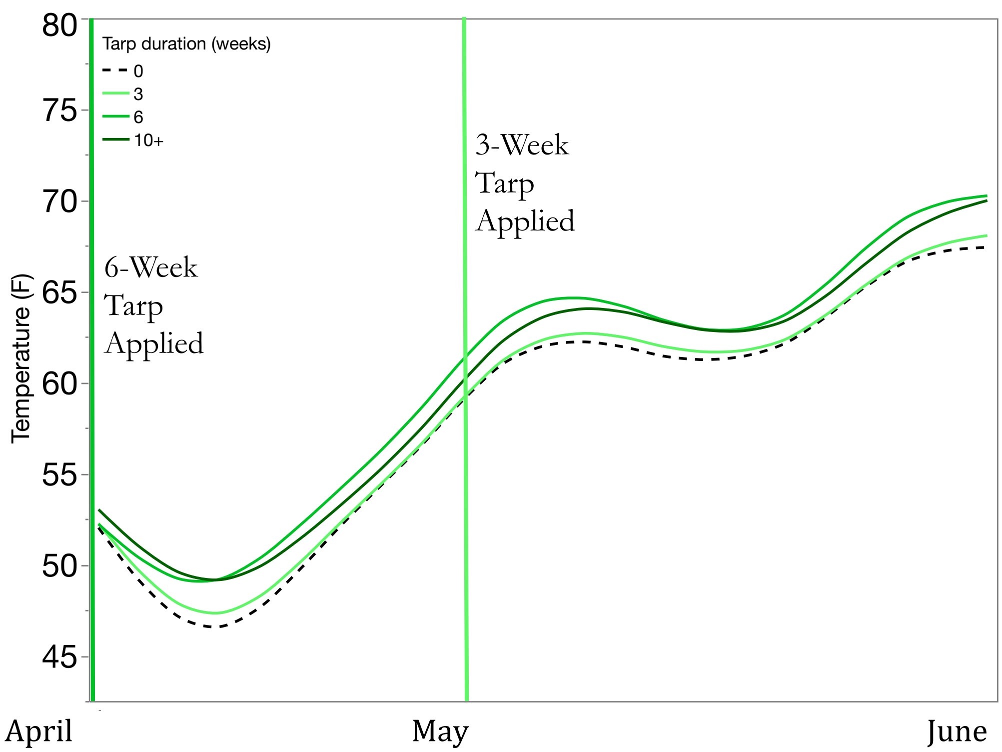


Figure A7. Soil temperature (F) at a 10 cm depth in Riverhead, NY for 0, 3, 6, and 10+ week tarp treatments. Data are averaged across two years: 2017, 2018.

Table A3. Weed parameters in Freeville, NY for Plantings 1 (P1) and 2 (P2) in 2017 and 2018.

Year	Factor	Level	P1 Weed % Cover	P1 10-Day Weed Count (m^{-2})	P1 10-Day Biomass ($g \cdot m^{-2}$)	P1 Above Canopy (m^{-2})	P1 Harvest Biomass ($g \cdot m^{-2}$)	P2 Weed % Cover	P2 10-Day Weed Count (m^{-2})	P2 10-Day Biomass ($g \cdot m^{-2}$)	P2 Above Canopy (m^{-2})	P2 Harvest Biomass ($g \cdot m^{-2}$)
2017	Tillage (T)	Conv.	--	--	--	43	86.7 b	--	--	--	23 a	56.8 a
		Reduced	--	--	--	36	79.4 a	--	--	--	--	128 a
		None	--	--	--	--	425 a	--	--	--	--	449 b
			--	--	--	NS	***	--	--	--		***
	Tarp (TD)	None	12 a[z]	--	--	24 a	206	59 a	--	--	--	312 a
		Short	0 b	--	--	24 a	177	0 b	--	--	18 a	143 b
		Mid	0 b	--	--	36 a	188	0 b	--	--	26 a	194 b
		Long	0 b	--	--	75 b	219	0 b	--	--	22 a	194 b
			***	--	--	***	NS	***	--	--	--	**
		TxTD	NS	--	--	NS	NS	NS	--	--	--	**
2018	Tillage (T)	Conv.	--	93 b	0.31 b	11	81.9 b	--	17 b	0.1 b	13 a	179 a
		Reduced	--	162 ab	0.83 ab	14	133 a	--	66 a	0.4 a	10 a	199 a
		None	--	236 a	1.6 a	13	112 ab	--	64 a	0.5 a	10 a	183 a
			--	***	***	NS	**	--	***	**	NS	NS
	Tarp (TD)	None	64 a	110 a	1.2	10 a	125	95 a	33	0.7 a	13	202
		Short	1 b	186 a	0.99	16 a	110	0 b	58	0.2b	9	142
		Mid	0 b	179 a	0.70	10 a	97.5	0 b	47	0.2 b	11	170
		Long	0 b	181 a	0.71	15 a	104	0 b	58	0.2 b	11	234
			***	*	NS	*	NS	***	NS	***	NS	NS
		TxTD	--	NS	NS	NS	NS	--	NS	*	**	*

[z]Mean separation by Tukey HSD at $P \leq 0.05$.

[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table A4. Weed parameters in Monmouth, ME for Plantings 1 and 2 in 2017 and 2018. Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm).

			P1				P2			
			Weed % Cover	10-Day Biomass (g·m^{-2})	Above Canopy (m^{-2})	Harvest Biomass (g·m^{-2})	Weed % Cover	10-Day Biomass (g·m^{-2})	Above Canopy (m^{-2})	Harvest Biomass (g·m^{-2})
2017	Tillage (T)	Conv.	--	--	8 a	108 b	--	--	8 ab	159 b
		Reduced	--	--	8 a	153 a	--	--	5 a	222 a
		None	--	--	17 b	255 a	--	--	11 b	333 a
			--	--	***	NS	--	--	*	**
	Tarp (TD)	None	33 b[z]	--	23 b	355 b	98 b	--	14 b	481 b
		Short	0 a	--	7 a	116 a	5 a	--	7 a	246 a
		Mid	0 a	--	5 a	76 a	2 a	--	7 a	109 a
		Long	0 a	--	10 a	141 a	2 a	--	4 a	115 a
			***	--	***	**	***	--	***	***
		TxTD	--	--	**	**	--	--	**	***
2018	Tillage (T)	Conv.	--	173 a	33 a	192 b	--	92 a	6 ab	215 a
		Reduced	--	199 a	33 a	115 a	--	109 a	8 a	237 a
		None	--	177 a	59 b	105 a	--	140 a	3 b	253 a
			--	NS	***	***	--	NS	*	NS
	Tarp (TD)	None	86 b	191 a	66 b	235 b	100 b	180 b	8 b	435 b
		Short	4 a	171 a	28 a	82 a	4 a	115 a	6 ab	157 a
		Mid	3 a	154 a	35 a	133 a	3 a	84 a	3 a	105 a
		Long	3 a	214 a	38 a	99 a	3 a	77 a	5 ab	245 a
			***	NS	***	***	***	***	**	***
		TxTD		NS	***	***		NS	**	***

[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05, 0.01, 0.001$ respectively.

Table A5. Weed parameters in Riverhead, NY in 2017 and 2018. Tillage is: reduced (3-8 cm) and conventional (10-20 cm).

			Weed % Cover	10-Day Weed Count (m^{-2})	10-Day Biomass ($g \cdot m^{-2}$)	Harvest Biomass ($g \cdot m^{-2}$)
2017	Tillage (T)	Conv.	--	--	--	279 a
		Reduced	--	--	--	328 a
			--	--	--	NS
	Tarp (TD)	None	0.31 a[z]	--	--	416 a
		Short	0 b	--	--	281 b
		Mid	0 b	--	--	200 b
		Long	0 b	--	--	316 ab
			***	--	--	**
		TxTD	--	--	--	**
2018	Tillage (T)	Conv.	--	5 a	0.16 a	155 a
		Reduced	--	32 b	1.1 b	198 a
			--	***	*	NS
	Tarp (TD)	None	0.07 a	71 a	2.7 a	206 a
		Short	0 b	0 b	0 b	158 a
		Mid	0 b	0 b	0 b	181 a
		Long	0 b	2 b	0.02 b	159 a
			***	***	**	NS
		TxTD		***	**	NS

[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table A6. Beet yield parameters in Freeville, NY for Plantings 1 (P1) and 2 (P2) in 2017 and 2018. Harvest yield calculated by combining Classes 1, 2, and 3 of beet size for 'marketable yield.' Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm).

			P1				P2			
			10-Day Stand (m^{-2})	24-Day Stand (m^{-2})	Harvest Stand (m^{-2})	Harvest Yield ($g \cdot m^{-2}$)	10-Day Stand (m^{-2})	24-Day Stand (m^{-2})	Harvest Stand (m^{-2})	Harvest Yield ($g \cdot m^{-2}$)
2017	Tillage (T)	Conv.	45	--	44	4026	37	--	46	2721
		Reduced	46	--	44	3713	36	--	44	2277
		None	--	--	--	--	--	--	--	--
			NS	--	NS	NS	NS	--	NS	NS
	Tarp (TD)	None	32 b[z]	--	35	3130 a	25 a	--	28 a	842 a
		Short	50 a	--	43	3912 ab	40 b	--	51 b	3174 b
		Mid	50 a	--	45	3767 ab	36 ab	--	45 b	2665 b
		Long	53 a	--	51	4679 b	45 b	--	56 b	3314 b
			**	--	NS	**	**	--	***	***
		TxTD	NS	--	NS	NS	*	--	NS	*
2018	Tillage (T)	Conv.	75 b	59 b	35 b	2477 a	115	104	87 a	1747 a
		Reduced	72 b	60 b	34 b	1532 b	103	94	74 b	1581 ab
		None	119 a	92 a	47 a	1260 b	101	94	72 b	1261 b
			***	***	***	***	NS	NS	*	*
	Tarp (TD)	None	74 c	50 b	26 b	972 c	57 b	64 b	50 b	855 c
		Short	101 a	84 a	46 a	1819 b	125 a	120 a	90 a	2052 a
		Mid	94 ab	69 a	41 a	1837 b	121 a	102 a	84 a	1755 ab
		Long	86 bc	77 a	42 a	2397 a	122 a	104 a	87 a	1456 b
			***	***	***	***	***	***	***	***
		TxTD	***	***	***	*	**	NS	NS	**

[z]Mean separation by Tukey HSD at $P \le 0.05$.
[NS], *, **, *** Not significant or significant at $P \le 0.05$, 0.01, 0.001 respectively.

Table A7. Beet yield parameters in Monmouth, ME for Plantings 1 (P1) and 2 (P2) in 2017 and 2018. Harvest yield calculated by combining Classes 1, 2, and 3 of beet size for 'marketable yield.' Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm).

			P1				P2			
			10-Day Stand (m^{-2})	24-Day Stand (m^{-2})	Harvest Stand (m^{-2})	Harvest Yield ($g \cdot m^{-2}$)	10-Day Stand (m^{-2})	24-Day Stand (m^{-2})	Harvest Stand (m^{-2})	Harvest Yield ($g \cdot m^{-2}$)
2017	Tillage (T)	Conv.	82	--	120	2416	--	--	85 ab	5037
		Reduced	82	--	126	2078	--	--	88 a	5130
		None	88	--	98	1938	--	--	70 b	4225
			NS	--	NS	NS	--	--	*	NS
	Tarp (TD)	None	53 b	--	63 b	787 b	--	--	23 b	2343 c
		Short	93 a	--	133 a	2318 a	--	--	100 a	5451 ab
		Mid	106 a	--	152 a	2386 a	--	--	104 a	4569 b
		Long	84 a	--	111 a	3085 a	--	--	96 a	6827 a
			***	--	***	***	--	--	***	***
		TxTD	NS	--	NS	NS	--	--	NS	*
2018	Tillage (T)	Conv.	--	48 ab	46	2391 b	--	26 b	26	788
		Reduced	--	46 a	43	1726 ab	--	34 a	26	618
		None	--	53 b	44	2391 a	--	33 a	22	618
			--	*	NS	***	--	*	NS	NS
	Tarp (TD)	None	--	33 c	23 c	1209 b	--	18 b	12 b	124 c
		Short	--	61 b	60 b	2126 a	--	38 a	29 a	696 b
		Mid	--	51 a	47 a	1635 ab	--	36 a	29 a	1129 a
		Long	--	50 a	47 a	2043 ab	--	32 a	28 a	750 ab
			--	***	***	*	--	***	***	***
		TxTD	--	***	***	NS	--	***	*	NS

[z]Mean separation by Tukey HSD at $P \leq 0.05$.

[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

Table A8. Beet yield parameters in Riverhead, NY for weeded and unweeded treatments in 2017 and 2018. Harvest yield calculated by combining Classes 1, 2, and 3 of beet size for 'marketable yield.' Tillage is: reduced (3-8 cm) and conventional (10-20 cm).

			Weeded			Not Weeded		
			10-Day Stand (m^{-2})	Harvest Stand (m^{-2})	Harvest Yield ($g{\cdot}m^{-2}$)	10-Day Stand (m^{-2})	Harvest Stand (m^{-2})	Harvest Yield ($g{\cdot}m^{-2}$)
	Tillage (T)	Conv.						
			82	120	2416	--	85 ab	5037
		Reduced	82	126	2078	--	88 a	5130
		None	88	98	1938	--	70 b	4225
			NS	NS	NS	--	*	NS
2017	Tarp (TD)	None	53 b[z]	63 b	787 b	--	23 b	2343 c
		Short	93 a	133 a	2318 a	--	100 a	5451 ab
		Mid	106 a	152 a	2386 a	--	104 a	4569 b
		Long	84 a	111 a	3085 a	--	96 a	6827 a
			***	***	***	--	***	***
		TxTD	NS	NS	NS	--	NS	*
	Tillage (T)	Conv.						
			--	46	2391 b	--	26	788
		Reduced	--	43	1726 ab	--	26	618
		None	--	44	2391 a	--	22	618
			--	NS	***	--	NS	NS
2018	Tarp (TD)	None	--	23 c	1209 b	--	12 b	124 c
		Short	--	60 b	2126 a	--	29 a	696 b
		Mid	--	47 a	1635 ab	--	29 a	1129 a
		Long	--	47 a	2043 ab	--	28 a	750 ab
			--	***	*	--	***	***
		TxTD	--	***	NS	--	*	NS

[z]Mean separation by Tukey HSD at $P \leq 0.05$.
[NS], *, **, *** Not significant or significant at $P \leq 0.05$, 0.01, 0.001 respectively.

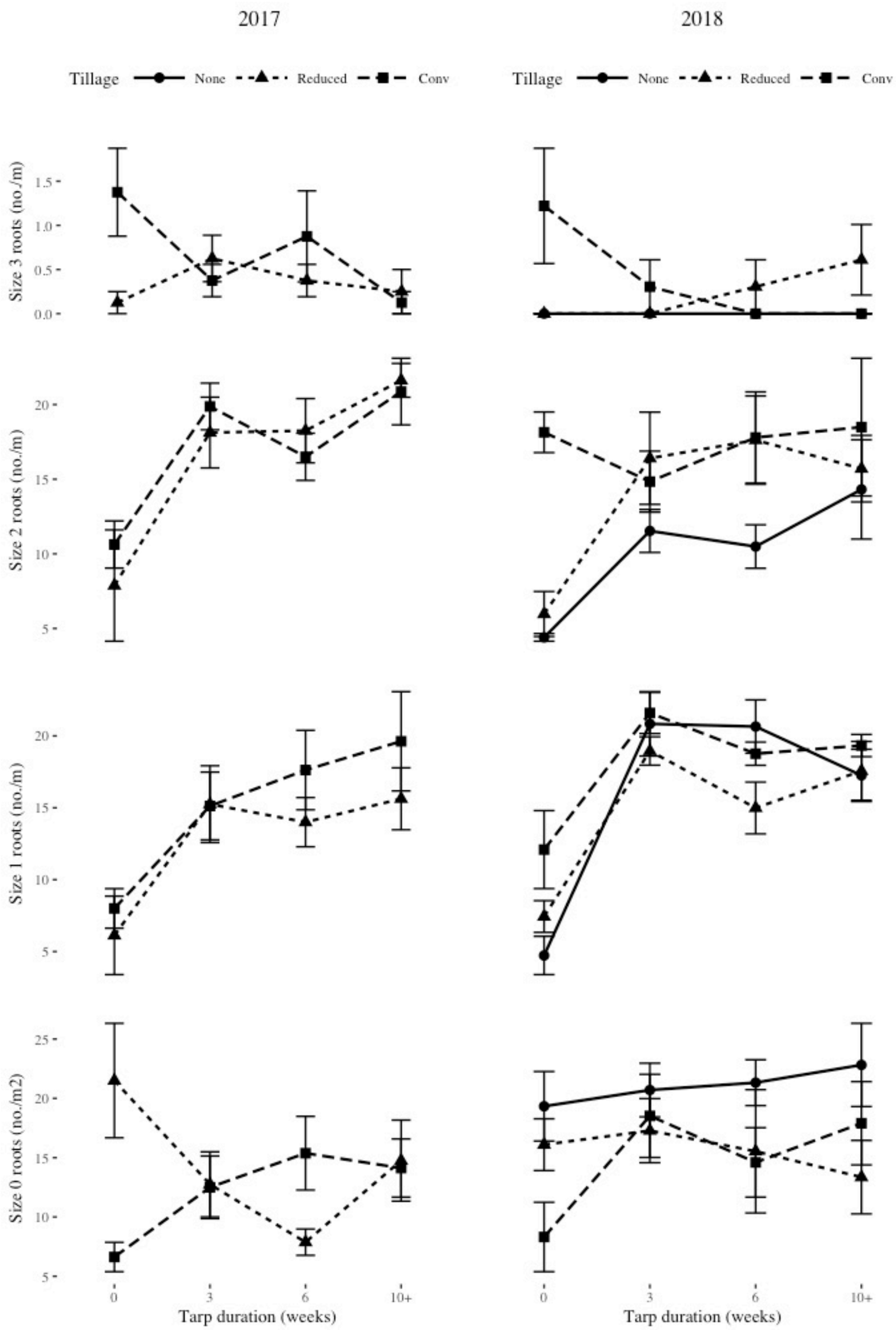


Figure A8. The effect of tillage and tarp duration on the number of table beet roots (cv. Boro) in Freeville, NY in different size classes in 2017 and 2018 averaged across two plantings; size 0 (<1.9 cm diameter), size 1 (>1.9 to <3.8 cm diameter), size 2 (>3.8 to < 7.2 cm diameter), and size 3(>7.2 cm diameter). Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm). Data were not collected in no till plots in 2017. Vertical bars are one standard deviation from the mean.

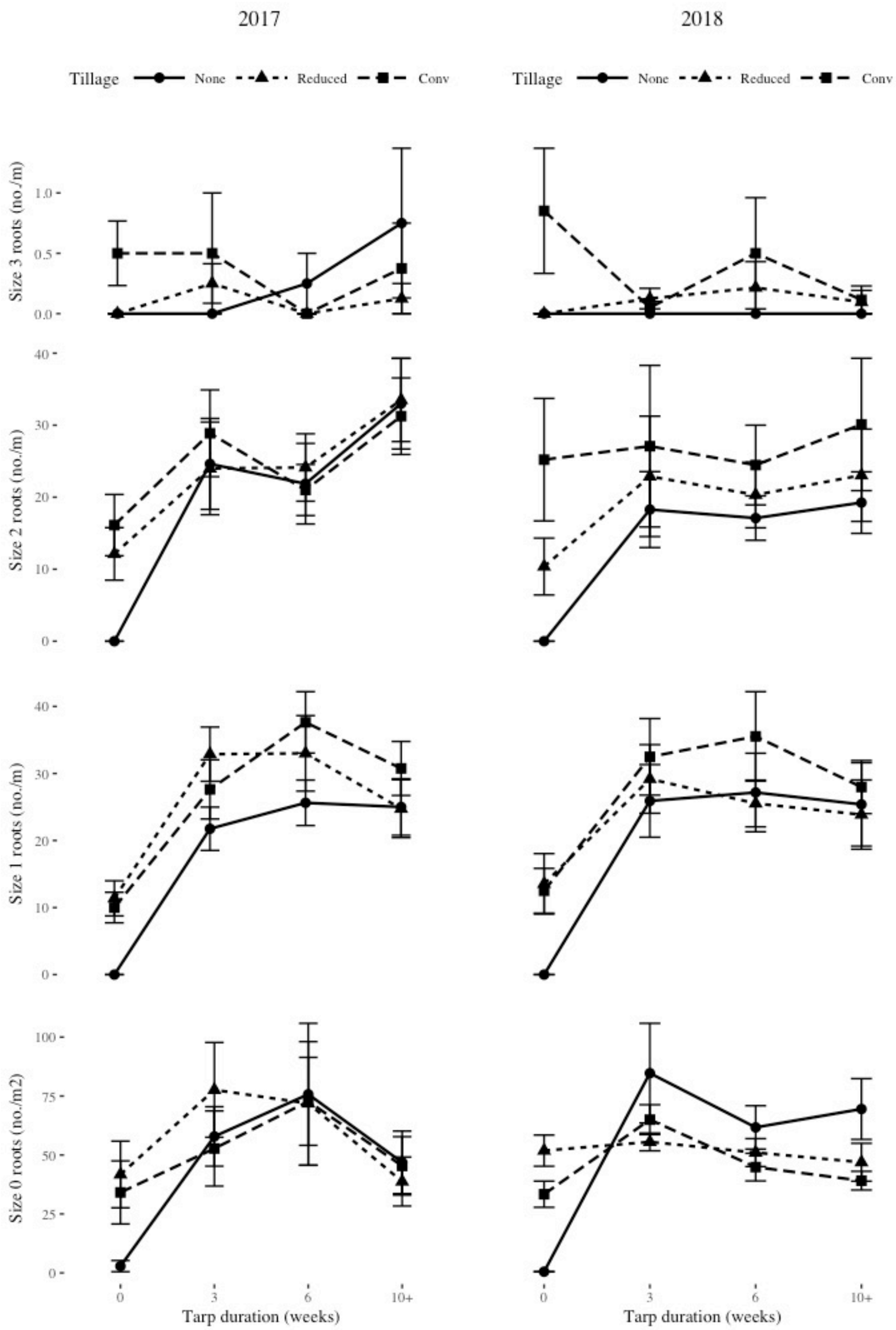


Figure A8. The effect of tillage and tarp duration on the number of table beet roots (cv. Boro) in Monmouth, ME in different size classes in 2017 and 2018 averaged across two plantings; size 0 (<1.9 cm diameter), size 1 (>1.9 to <3.8 cm diameter), size 2 (>3.8 to < 7.2 cm diameter), and size 3(>7.2 cm diameter). Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm). Vertical bars are one standard deviation from the mean.

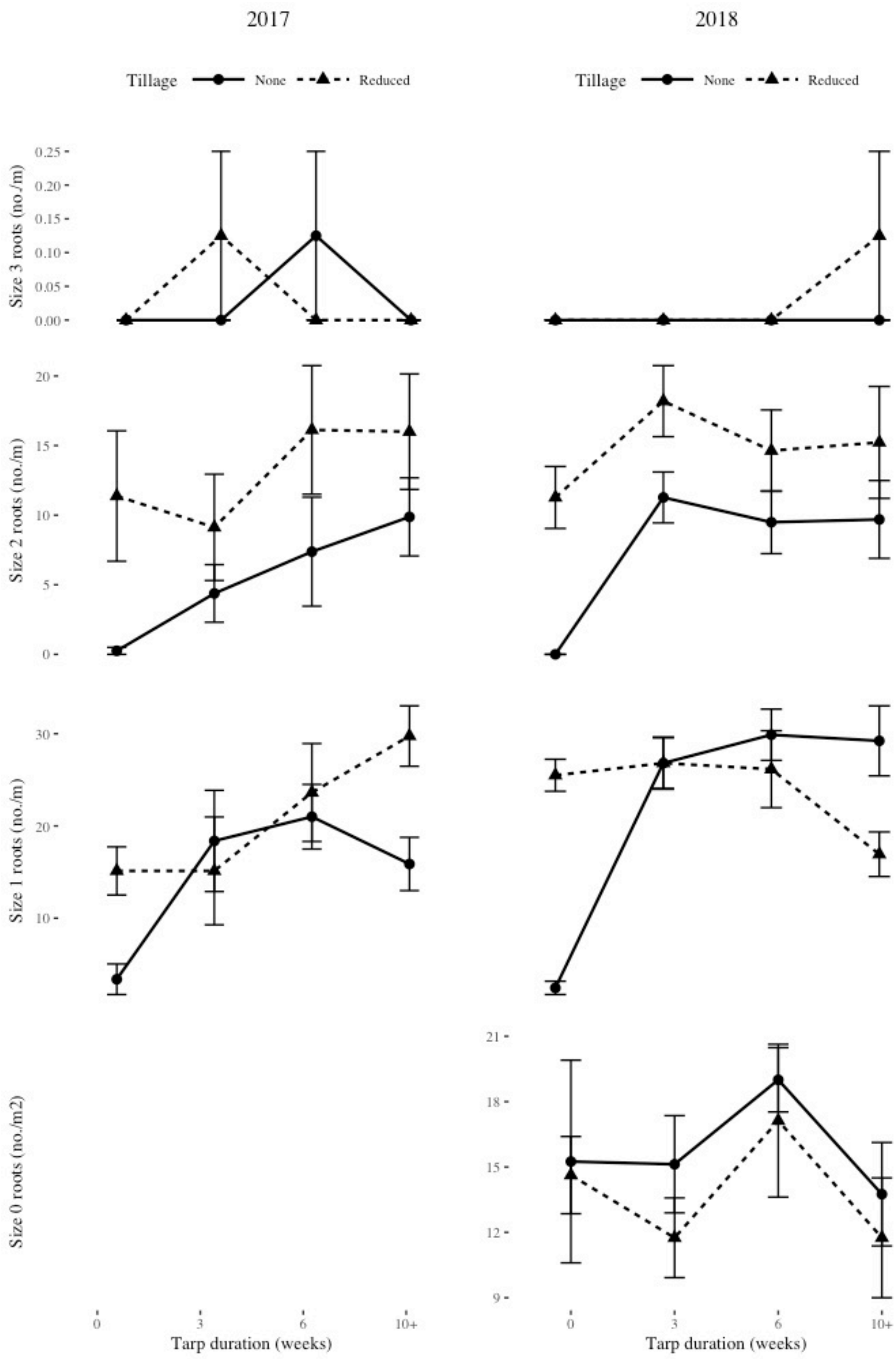


Figure A8. The effect of tillage and tarp duration on the number of table beet roots (cv. Boro) in Riverhead, NY in different size classes in 2017 and 2018 averaged across two plantings; size 0 (<1.9 cm diameter), size 1 (>1.9 to <3.8 cm diameter), size 2 (>3.8 to < 7.2 cm diameter), and size 3(>7.2 cm diameter). Tillage is: none (no till), reduced (3-8 cm), and conventional (10-20 cm). Data were not collected on size 0 roots in 2017. Vertical bars are one standard deviation from the mean.

OTHER MATERIAL

SFP Reduced Tillage Project

The Cornell Small Farms Program is working to find effective ways to reduce tillage on small farms throughout New York State through the Reduced Tillage project. Based at the Homer C. Thompson Research Farm in Freeville, NY, Small Farms Program staff Ryan Maher and Brian Caldwell have spearheaded the project for four years.

Tackling reduced tillage means finding alternative strategies to manage weeds. Weeds are problematic for small and large farms alike. Tillage can be an effective strategy for elimination of weeds, but can also damage soil health. Frequent and deep tillage can degrade soil structure over time, decreasing soil organic matter and moisture content and increasing erosion.

A strategy to combat weeds while maintaining soil health is using tarps. Tarping has become increasingly popular among small-scale farmers and can be used for a period of a few weeks in the spring to prepare a seedbed for planting, several months over-winter, or intermittently in the growing season. An article in the Spring 2018 Quarterly synthesized many benefits of tarping after several years of trials in Freeville.

Tarp Trials in Freeville, Local Farms

Over the past two years research trials in Freeville, NY, as well as in Long Island and Maine, have looked into the impact of tarps on the soil, weed pressure, and yield of direct-seeded beets. While crop and weed residue were not degraded by tarps in these experiments, soil nitrate concentrations increased significantly, and there were no living weeds present under tarps of any duration. Tarped plots kept lower weed pressure for two weeks, and at the end of the season, tarped plots had almost no perceptible difference between tillage treatments for beet yield or weed pressure, whereas untarped plots had significant differences between tillage treatments.

These trials with beets show benefits of tarp use, but are these results generalizable to working farms? Cornell University master's student, Haley Rylander, partnered with small farms throughout New York State to observe the functionality of tarp use.

Haley worked with several farms in the Finger Lakes region, and found positive results and feedback from area farmers. The incorporation of tarping into their farming systems was a learning curve, but the local farmers found weed suppression and better regulated soil moisture as benefits making tarp use worthwhile.

Centurion Farm

Locke, NY is home to Centurion Farm owned by Nina and Jeff Saeli. The Saelis had not used tarps previously, but found increased soil moisture in tarped beds compared with bare soil, and some reduction in weed pressure.

They planted two crops to compare the impact of tarp use: dry beans and onions. The onion beds were prepared the previous fall, tarped for 3-4 weeks in spring, and then planted into (without further bed preparation) as soon as the tarps were removed. Since onions were planted early, the tarps went on early. Therefore, the ground underneath the tarp did not heat up as much as other trials.

Tarps were applied later for the dry beans. The difference in soil moisture between tarped and untarped beds was more noticeable in the bean plots. In addition to soil moisture, Nina and Jeff found that the untarped bean plots had significantly more weeds.

"Even though it hasn't shown to be successful to help us reduce our tillage because it's too early, I can tell you that the weed suppression alone makes the tarp worth it," Nina said. "When I timed myself when I weeded, on the tarped beans, it literally took me more time to walk the beds to look for weeds than it took me to actually weed. And if there was a weed, it was something that just got snapped up easy with a linear hoe."

Nina and Jeff said they will be using tarps next growing season. They hope to be able to reduce tillage as they create systems with tarp use. A strategy they have for managing the heavy tarps is to cut their 50'x40' tarps in half to make folding and handling of the tarps easier.

Muddy Fingers Farm

Liz Martin and Matthew Glenn own Muddy Fingers Farm in Hector, NY. They tarped their beds 4-5 weeks before planting beets and found that the tarps retained soil moisture better on their farm as well. Their tarped and untarped beds received the same amount of water throughout the season, yet the plants in the tarped beds had much better stand counts.

Tarps were also useful for weed suppression. The beds were tilled before placing the tarps, and the ground had green weeds. When tarps were removed before planting, everything was dead leaving a fresh bed for planting.

Liz and Matthew use cover crops on their farm and have found that tarps can sometimes be used in place of a cover crop, or used to kill a cover crop before planting. They already try to reduce tillage, but have found that these methods help in reducing tillage within their system.

From a soil health standpoint, Liz recommends tarping. She says that tarping opens up options for farmers by bringing up earthworms and nutrients. While suggesting that everyone tries it if even only considering tarping, Liz cautions that planning ahead is crucial. Successfully implementing tarps requires that your planting schedule fits with a 4- to 6-week window of tarps being down.

Plowbreak Farm

Perennial weed suppression has been a benefit of using tarps for Aaron and Cara Munzer of Plowbreak Farm in Hector, NY. In their second year of using tarps, they said it's better than any other tillage or control methods that they've tested for perennial control. For the Munzers, tarping has been especially helpful in establishing a new farm by combatting thistle and quackgrass.

The Munzers prep their seedbeds before laying down the tarps, then plant directly into the beds after tarp removal. Although not a perfect solution, Aaron said tarping "does really wipe out the majority of the seed bank in the top strata of the soil." Soil moisture was retained under their tarps, and soil life seemed undisturbed.

Worms and bugs were able to survive while any living plant material under the tarp was killed.

Similar to Muddy Fingers Farm, Aaron states that tarping doesn't add to the flexibility of his farm and requires planning. When not in use, tarps are rolled up on the edge of beds. Tarps are no silver bullet, but Aaron said tarping is "a tool in our tool belt of options to keep weeds down and to practice some reduced tillage."

Rise and Root Farm

Tarps aren't a new sight on the black dirt of Rise and Root Farm, but Jane Hodge, Karen Washington, and Michaela Hayes continue to reap the benefits of tarps on their Hudson Valley farm. They laid tarps for 3.5 weeks prior to planting dill, cilantro, and Thai basil. The tarped beds required no early-season weeding in comparison to the untarped beds, which required 2 hours of hand-weeding. Jane, Karen, and Michaela tilled before tarp application and used a broadfork after tarp removal to loosen soil due to severe compaction from earlier in the season.

Jane said the contrast between the soil under the tarps and the surrounding ground was striking.

"The bed underneath was weed free and ready to plant," she said. "We actually had to weed whack around the bed because the surrounding weeds had gotten so out of control.

Further Information

The trials in Freeville combined with area farms found increased soil moisture, elevated nitrate levels, weed suppression, and the ability to reduce tillage as benefits of adding tarping to your system. Further information on tarping and other reduced tillage practices can be found on the Small Farms Program website's Reduced Tillage project page.

TARP FACT SHEET FALL 2018

Fact Sheet

TARPS TO SUPPRESS WEEDS AND REDUCE TILLAGE

How black polyethylene plastic can suppress weeds, preserve soil moisture, and prepare beds for planting.

Produced by Haley Rylander for the Cornell Small Farms Program

What Tarps Do

Tarps, commonly known as 'silage tarpes,' are placed on the soil surface a number of weeks or even months prior to cash crop planting. They kill weeds, prevent emergence of living weeds, and can spark fatal germination of some species. They can allow farmers to get into the field a little earlier in the spring by keeping the soil at a more even moisture.

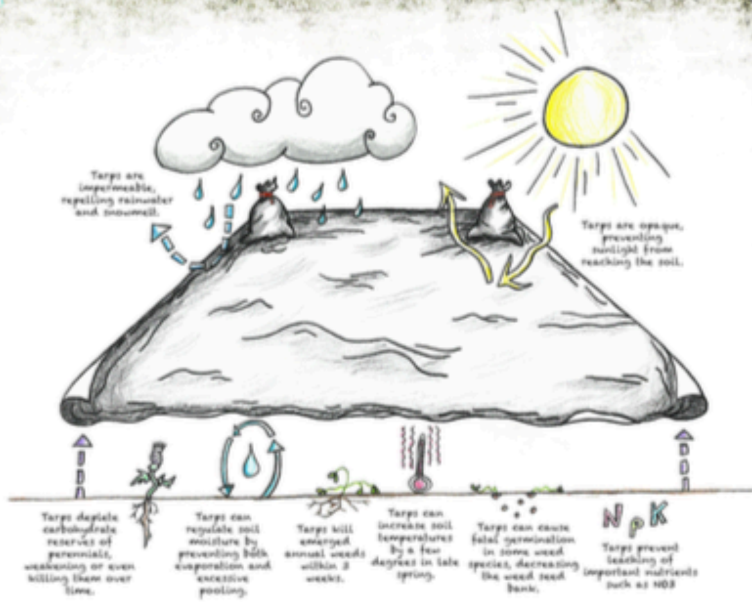
Tarps can also facilitate reduced tillage. Intensive tillage degrades soil structure, increases erosion, and decreases soil organic matter and moisture. Tarps can help reduce tillage by providing many of the same benefits and providing a weed-free bed in which to plant.

How These Tarps are Different

Silage tarps should be 6 mil weight, polyethylene plastic, black on at least one side, and treated for UV resistance.

Unlike landscape fabric, tarps are impermeable, preventing all sunlight and water from reaching weeds and seeds on the soil surface. Tarps are more effective at killing weeds and prevent leaching of nutrients from rainfall.

Tarps are thicker than plastic mulch and last much longer. They are not in the field when a crop is in place and require no specialized equipment.



How to Use a Tarp

Tarps can be laid over fully prepared soil (tilled, amendments added, etc.), over bare ground, over mature weeds, or over a mowed cover crop. They should be left in place at least three weeks to gain the most benefits, but can be kept in place for months. Perennial weeds may take much longer than three weeks to kill.

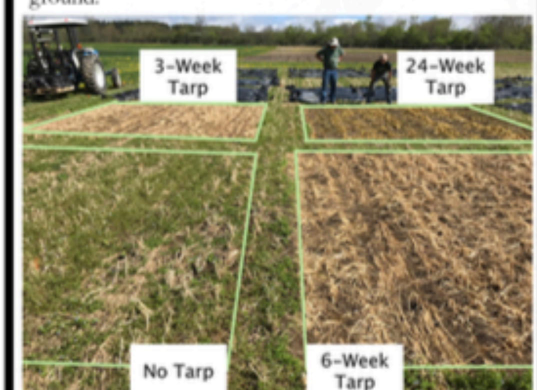
Some farmers leave tarps on over winter to protect the soil from erosion and leaching. Many recommend preparing the soil before laying a tarp so as to not re-introduce new weed seeds by disturbing the soil after the tarp is removed.

White-thread stage seedlings that emerged under a tarp in late-spring, only to be killed by lack of light.

Research

Trials at the Homer Thompson Research Farm in Freeville, New York found that no weeds were present under any tarp of a three week duration or longer. Weed pressure remained significantly lower in tarped plots for ten days. At the end of the season, beet yield was increased by use of tarps, and the difference between reduced and conventional tillage was reduced for both **yield and** weed pressure when tarps were used.

Researchers also found that nitrate concentrations were significantly higher in tarped plots campared with bare ground.



Logistics of Tarps

Storage:
Tarps can be folded and stored in a shed, but most farmers keep them in the field. Tarps can be rolled and weighed down in between rows or at the edges of fields for added weed suppression.

Handling:
Most tarps are 100 feet long and vary in width from 24-50 feet, weighing between 50 and 120 lbs. Some farmers cut them in half legnthwise to make handling easier for two people. Avoid laying tarps on windy days!

Securing Edges:
Tarps are secured to the soil surface with heavy objects such as sandbags, rocks, or concrete slabs. Some farmers put shovels of soil around the edges.

Planning:
Tarps require some advanced planning to incorporate into cropping plans. Look ahead and decide which crops and fields could benefit from a tarp and how many weeks you can spare. Cover crops, snow cover, temperature, weed life cycles, and crop planting should all be considered when deciding the timing and duration of a tarp.

Farmer Stories

Liz Martin
Muddy Fingers Farm
Schuyler County
New York

"It's been fun to try and to see how clean you can get - especially if you have a weedy spot. We've definitely tarped over weeds and then just left it, and then it's neat to see how it breaks them down to nothing."

Aaron Munzer
Plowbreak Farm
Schuyler County
New York

"I would say it's been a learning curve. We... found that tarps are especially effective for killing grass and sort of readying planting beds - maintaining moisture levels. But as far as weed control, we're still learning about how to use them most effectively."

Nina Saeli
Centurion Farm
Cayuga County
New York

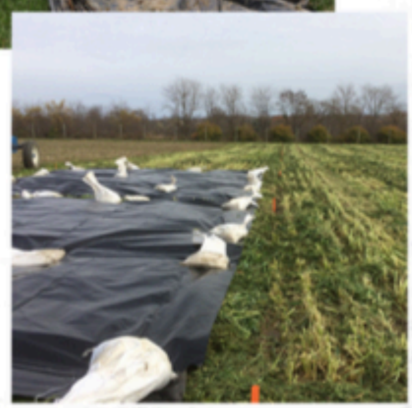
"I can tell you that the weed suppression alone makes the tarps worth it. When I timed myself when I weeded, on the tarped beans, it literally took me more time to walk the beds to look for weeds than it took me to actually weed."

Buying a Tarp

Most farm supply stores carry 100ft silage tarps. They are also available from Johnney's Selected Seed.

Tarps range in price from $100-290 depending on the width and the supplier. Widths range from 24-50ft.

Buy 6 mil polyethylene tarps, black on at least one side, that have been treated for UV resistance. Silage tarps with this treatment generally have a 5 year warranty.



Summary

Tarps can be a great tool to help suppress weeds, regulate soil moisture, and reduce tillage on a farm. There are numerous ways to make use of tarps, and individual farmers may have to experiment to see what methods work best on their farm. Try one out and help contribute to the growing knowledge of tarps!

For more information, visit the Small Farms website: www.smallfarms.cornell.edu/projects/reduced-tillage

This work is supported by the OREI Program (2014-51300-22244) and Smith Lever/Hatch Federal Capacity Funding (2017-18-122) from the USDA National Institute of Food and Agriculture, as well as the Toward Sustainability Foundation ***2017/18.***

SMALL FARMS BLOG POST FALL 2018

LOCAL FARMS TRIAL TARPING FOR REDUCED TILLAGE RESEARCH

As the growing season winds down, Haley Rylander, a masters student working with the reduced tillage project of the Cornell Small Farms Program, has been visiting with farmers who have taken an active role in her research. Haley shares some of these farmers' experiences and gives insight about using tarps to suppress weeds and reduce tillage on small farms.

There are few foolproof methods to control weeds, especially in organic agriculture where farmers cannot use herbicides. For these farmers, tillage is one of the best ways to reduce weed pressure, but intensive tillage degrades soil structure over time and leads to loss of organic matter and moisture from the soil. The reduced-tillage project team at the Cornell Small Farms Program have been talking with farmers in the northeast who are experimenting with innovative solutions to reduce weed pressure and conserve soil health in organic systems. We've been doing some research trials with one of these tools: black silage tarps placed on the soil surface prior to planting.

These tarps smother living weeds and can encourage the seed bank of other weeds to fatally germinate. Tarps also prevent leaching of nutrients and conserve moisture, while slightly heating the soil. Tarps can be used in combination with low-disturbance tillage to provide many of the same benefits as intensive tillage. The initial results of this research was recently published on eXtension.org.

To supplement our trials at Cornell University's Thompson Research Farm, we've been doing some on-farm trials with local growers in Central New York to see how tarps perform in real situations on real farms. Over the last few weeks, we've visited some of these farms to see how things have progressed as we near the end of the season. Three of these farms are local to the Cornell campus in Ithaca, NY: Centurion Farm, Muddy Fingers Farm, and Ploughbreak Farm.

These farmers used tarps for different lengths of time and on different crops, with whatever pre- or post-treatment of the soil they chose. Some tilled lightly before the tarps were applied, some tilled after, some had mowed cover crops before hand. It was all up to the farmers, as long as they used a tarp over a number of beds and compared their weed pressure and yield to that of un-tarped beds nearby.

From talking with these farmers about their experience with the trials, we have found some common themes. One of which is that tarps hold soil moisture at an ideal level.

"A drier area stayed pretty dry, even in rainstorms, and if it was a wetter area, the moisture sort of evened out," Aaron Munzer from Ploughbreak Farm said of the soil moisture under tarps. "So it was actually pretty perfect for tillage or planting."

Liz Martin from Muddy Fingers Farm planted beets in this year's very dry July, and attributes her higher stands in tarped beds compared with untarped beds to better soil moisture.

One of the biggest benefits of tarps is their ability to suppress weeds. Nina Saeli from Centurion Farm said that the weed suppression alone makes the tarps worth it.

"I timed myself when I weeded, on the tarped beans, it literally took me more time to walk the beds to look for weeds than it took me to actually weed," Nina said. "On the untarped side with the beans, it was much more difficult, and I spent a lot more time weeding … once I let that side get a little away from me, I was on my hands and knees pulling those weeds up when I was not doing that on the tarped side."

Several of the farmers commented on the ability of tarps to control perennial weeds, though it may take many more weeks or even months longer than the three weeks required to kill most annuals. Weed suppression from tarps does not seem to be a season-long effect. However, Liz said it was fun to see how clean she could get her beds. She also noted that they had tarped over weeds "and then just left it, and then it's neat to see how it breaks them down to nothing."

The farmers say there is definitely a learning curve in terms of figuring out how to incorporate tarps into their cropping plans and determining which crops and timings work best on their farms. In general, prepping beds before tarping seems to have the most positive effects, as tilling after tarping brings up more weed seeds.

Tarps are no miracle solution to eliminate tillage and weeds, but growers seem excited about using them and learning more about the benefits they can provide in a small farming system. When asked their overall opinion of tarping here were some responses:

"It's a great tool. Even if you're considering, I recommend people give it a try." – Liz Martin

"The results we've seen so far have encouraged us and we actually went out and bought two tarps." – Nina Saeli

"I don't think it's a perfect solution for a 6-acre farm. I think tillage is still required… on our farm, [but] I think it's a tool in our tool belt of options to keep weeds down and to practice some reduced tillage." – Aaron Munzer eORGANIC ARTICLE SUMMER 2018

REUSABLE BLACK TARPS SUPPRESS WEEDS AND MAKE ORGANIC REDUCED TILLAGE MORE VIABLE

Introduction

Organic vegetable farmers rely heavily on intensive soil tillage to control weeds, incorporate amendments and cover crop residue, and prepare clean seedbeds. Intensive tillage, however, can decrease long-term soil health by causing compaction and loss of soil structure, organic matter, and moisture. Tillage can also be costly to farmers by consuming time, fuel, and labor. Reduced tillage is particularly difficult to incorporate into organic systems because farmers cannot use herbicides to control weeds. The use of black, impermeable, plastic tarps placed on the soil surface prior to planting could reduce weed pressure, decompose crop residue, and preserve prepared soil for several weeks. This article assesses the potential uses of tarps in organic vegetable systems to reduce or even replace tillage by controlling weeds and decomposing crop residue.

Figure 1. A black plastic tarp laid over full-length crop beds. *Photo credit: Haley Rylander*.

Use of Plastic in Farming

The use of synthetic soil covers, including plastic, is already a common, long-studied practice in both organic and conventional production. Transparent plastic sheets are widely used in times of bright sunlight as temporary soil covers for solarizing soils—a physical method that raises surface temperature to extremes that kill weeds and pests (Abu-Gharbieh et al., 1988; Link, 1994). Soil solarization, however, needs extreme heat in order to be effective at weed suppression, thus limiting this approach as a viable option in the Northeastern United States.

Black plastic mulch and landscape fabric are also well-known synthetic covers for suppressing weeds, conserving soil moisture, raising soil temperatures, and increasing crop productivity (Kasirajan and Ngouajio, 2012). Unlike mulches and landscape fabrics, tarps do not remain in place for planting, but are used for short periods throughout the seasons between plantings. Similar to mulches, plastic tarps impact the temperature, moisture, and nutrient profile of the soil as well as weeds and residue.

Why not simply use landscape fabric for pre-planting tarping? Landscape fabric may provide some of the same benefits as thicker, impermeable tarps, but it does not create the same soil environment nor does it affect weeds in the same way. Weeds can root down into landscape fabric if seeds land on its surface, and some weeds can even break through the fabric from underneath. Landscape fabric also allows water and airflow to the soil surface, enabling leaching and taking longer to kill weeds that have already emerged.

Tarp Logistics and Benefits

One of the most common questions we receive from farmers is “what exactly is a tarp?” A tarp in this context is a large, moveable sheet of thick black plastic that is impermeable to water. It can be rolled or folded and stored when not in use, and lasts many years if handled with care. Tarps can be cut to any size, but are typically around 100 ft long and wide enough to cover one or multiple beds in a field (from 10–30 ft) (Fig. 1). Available labor should be considered when choosing a tarp size, as very large tarps can weigh up to 50—75 lbs and may be difficult to maneuver with just one or two people. On the whole, however, tarps do not require a significant number of people to lay on the soil or store, do not take long to apply, and are relatively cheap ($100 for a 100 x 24 ft tarp). Choosing days with minimal wind is helpful when laying tarps.

Tarps are secured with heavy objects such as sandbags or stones placed around the edges. There is no need to form a seal on the edges. Tarps can be applied to fully-prepared soil (lightly tilled, amendments added, residue incorporated, etc.), or laid directly over a mowed cover crop or weeds, and can be left in place for any length of time, though most beneficial effects need at least three weeks.

Unlike tillage, tarp application is not dependent on weather or soil conditions. Using tarps conserves fuel use, labor hours, and soil compaction from heavy machinery. Soil is left undisturbed and is able to conserve moisture, organic matter, and structure. Leaching and waterlogging from rain and snowmelt are also prevented.

Effects of Tarps

We have spoken with farmers and conducted experimental trials to assess the effects of tarps left on the soil for different lengths of time (from three weeks to overwinter) and in combination with no-till, shallow-till (1 in), and rototill (4 in) treatments after tarp removal.

Figure 2. An overwinter tarp pulled up in early spring shows no residue decomposition—some of the residue is still green. *Photo credit: Haley Rylander.*

Cover Crop Residue

It should be noted that tarps are not meant as a replacement for cover crops, as they do not add nutrients or organic matter to the soil. Many growers already using tarps have reported that cover crop residue completely decomposes when left underneath tarps for several weeks. We did not observe this in our trials. In fact, crop residue seemed to be almost preserved under our overwinter tarps (Fig. 2). This may be due to decreased surface temperatures throughout the winter. Many farmers who report residue decomposition also irrigate, add organic amendments, and/or finely chop or incorporate residue into the soil just before laying tarps, whereas our experiments left crop residue exactly as it was on the soil surface. It is likely that using water and amendments and incorporating crop residue prior to tarping increases soil microbial activity under the tarp, causing a more rapid decomposition of residue.

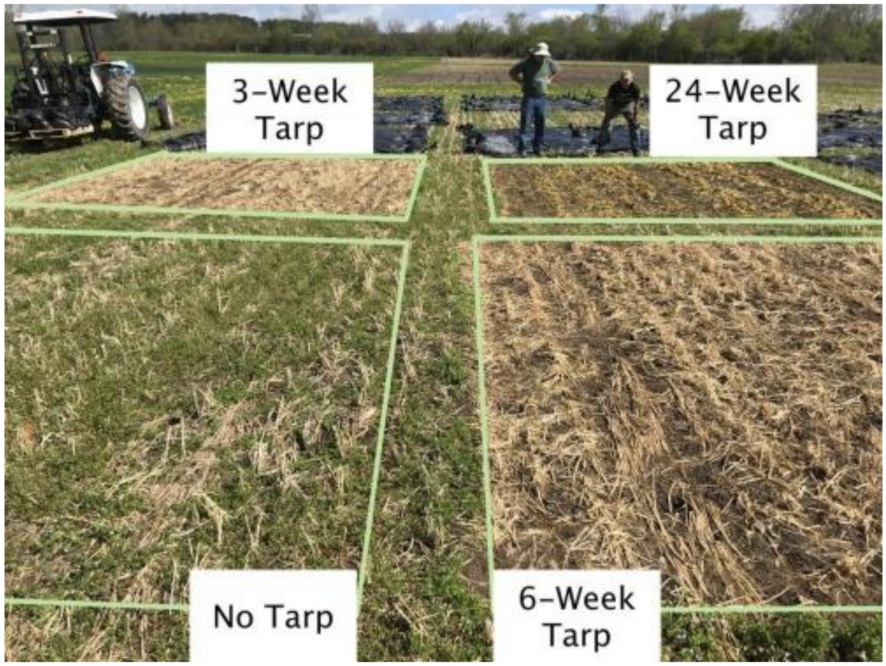


Figure 3. Four plots with different tarp treatments right after tarp removal in late spring. Clockwise: Tarp applied 3 weeks prior to planting, 24 weeks prior to planting (overwinter), no tarp applied, and 6 weeks prior to planting. *Photo credit: Haley Rylander.*

Weeds

Arguably the most important benefit of tarps is suppressing weeds prior to planting a crop. No weeds can germinate and survive underneath an opaque tarp, and any emerged weeds prior to tarp application are killed within three weeks due to light suppression. In our trials, there were no weeds present in tarped plots at the time of removal (Fig. 3), and 10 days after planting there was an average of 96% less weed biomass in tarped plots than untarped weedy control plots.

By the time of harvest in our experiment, there was no significant difference in weed biomass between tarp treatments. The same experiment in Monmouth, Maine and Riverhead, New York did show significantly lower weed biomass in tarped plots at the end of the season. Season-long weed suppression by tarps is still unclear, and may depend upon individual weed communities. It is clear, however, that tarping gives a beneficial head start to crop seeds or transplants.

Regardless of weed biomass, beet yield did increase with tarp use. Average beet yield in our early planting was 43-82% higher with use of tarps in shallow-till plots, and 7-26% higher with use of tarps in rototill plots. There was no marketable yield without tarps in shallow-till plots of our late planting, but with tarps, yield was comparable to that of rototill plots. Average yield in rototill plots was 59-98% higher with use of tarps in the late planting. These increases, despite comparable weed biomass across treatments, may be due to the early-season head start with decreased weed competition, or increased nitrogen concentrations in tarped plots.

A common question from farmers is whether tarps create a stale seedbed in which weed seeds are stimulated to germinate and then killed. It is clear that some weed seeds are in fact germinating underneath tarps because we have found small, stunted weed seedlings on the soil surface after tarp removal (Fig. 4). It is possible that increased temperatures and preserved moisture under tarps stimulates seed germination. However, the extent of this effect is not known. Tarps are often applied in early or late spring when the soil has not warmed and weed seeds have not begun to germinate. Tarps applied later in season, especially after light soil disturbance or watering, could potentially be used as a stale seedbed method. We did not experiment with this, but we did lay our 3-week late-planting tarp over already emerged weeds, and no living weeds were present at the time of tarp removal.

In our research trials, there was never a significant difference between tarp durations when it came to weed suppression or crop yield increase. From this, it can be assumed that laying a tarp just three weeks prior to planting should be enough to see the desired effects of weed suppression. We also found that using tarps for three or more weeks greatly reduced the difference in weed biomass and crop yield between shallow-tilled and rototilled plots. Using tarps, in other words, made shallow-tilling at 1 inch about as effective as rototilling at 4 inches, whereas non-tarped plots often had significantly fewer weeds and higher yield in rototilled plots than shallow-tilled plots.

Figure 4: Stunted weed seedlings on the soil surface under tarps. All seedlings were dead after a few hours of exposure. *Photo credit: Haley Rylander.*

Soil Environment

Water can flow under the edges of tarps to an extent, but rain infiltration and pooling or waterlogging by rain and snowmelt is prevented. Tarps hold soil moisture relatively constant throughout their duration. These effects may differ with sandier soil types, but in the gravelly loam of our experiment, soil moisture under tarps was retained throughout the season. Water will flow off of tarps, however, and where it flows should be considered. If possible, water should be directed towards perennial alleyways.

Soil temperature does not rise to extremely high temperatures under tarps, such as with soil solarization, but temperatures do rise a few degrees. This could potentially stimulate fatal weed seed germination and increase soil microbial activity.

Nitrogen Management

Plant-available nitrogen (NO_3 and NH_4) in the soil is extremely important to crop growth. With no amendments added, soil nitrate (ppm) increased significantly with tarp duration. Plots in Freeville, NY with a tarp duration of three weeks had an average of four times more nitrate than plots with no tarp, and an average of five times and nine times more nitrate with a duration of six weeks and ten weeks respectively (Fig. 5). Ammonium was not significantly affected, but nitrate is the primary form of nitrogen used by plants.

There are many possible explanations for this increase in nitrate. First, tarps prevent leaching. Nitrate is very soluble in water and leaches easily from the soil if not taken up by plants. Second, tarps prevent waterlogging of soil. Anaerobic environments can promote denitrification, in which soil microorganisms take oxygen from nitrate and convert it back to gaseous N_2. Third, even slightly increased soil temperature may be enough to promote microbial activity and mineralization/nitrification (conversion of atmospheric and organic nitrogen into a plant available form).

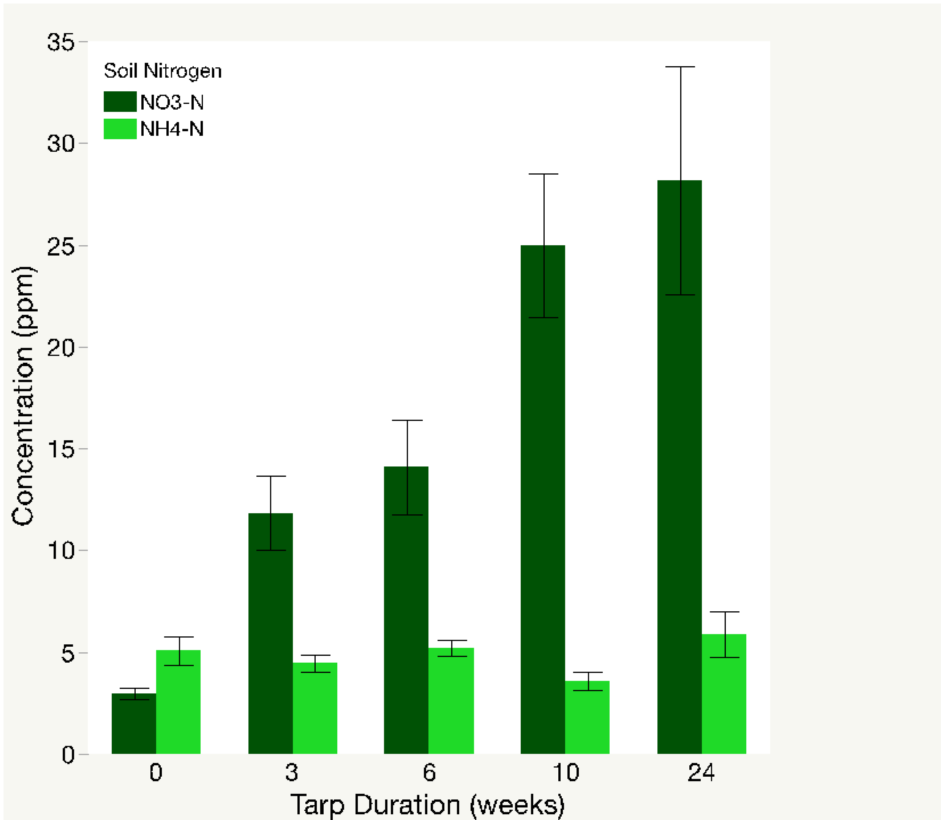


Figure 5: Concentration (ppm) of average soil nitrate (NO_3) and ammonium (NH_4) at the time of tarp removal in plots with tarp durations of 0-24 weeks prior to crop planting. Data taken in Freeville, NY.

Still To Learn

There is still a lot to learn about using tarps in farming systems. For example, we do not know how tarps may affect worms, microorganisms, fungi, or soilborne diseases. Does preparing the seedbed before tarp application provide more benefits than preparing it after tarp removal? Despite these unknowns, there are clear benefits to incorporating tarps into organic vegetable systems. Hopefully, further farmer experience and research can unlock the potential of this innovative tool.

Funding: NIFA-OREI and TSF grants

References and Citations

- Abu-Gharbieh, W. I., H. Saleh, and H. Abu-Blan. 1988. Use of black plastic for soil solarization and post-plant mulching [Online]. Plant Protection Department, Faculty of Agriculture, University of Jordan, Amman, Jordan. Available at: www.fao.org/docrep/t0455e/T0455E0j.htm(verified 22 Aug 2018).
- Kasirajan, S., and M. Ngouajio. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agronomy for Sustainable Development 32:501–529. Available online at: http://dx.doi.org/10.1007/s13593-011-0068-3 (verified 22 Aug 2018).
- Linke, K. H. 1994. Effects of soil solarization on arable weeds under Mediterranean conditions: Control, lack of response or stimulation. Crop Protection 13:115–120. Available online at: https://doi.org/10.1016/0261-2194(94)90161-9 (verified 22 Aug 2018).

This is an eOrganic article and was reviewed for compliance with National Organic Program regulations by members of the eOrganic community. Always check with your organic certification agency before adopting new practices or using new materials. For more information, refer to eOrganic's articles on organic certification.