Black Plastic Tarps Advance Organic Reduced Tillage II: Impact on Weeds and Beet Yield

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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. Placing opaque plastic tarps on the soil surface weeks or months before planting can reduce weed pressure and may facilitate organic reduced tillage strategies, but few studies have documented tarp effects on crop productivity. The effect of tarp duration and tillage intensity on weeds and beet crop yields (cultivar Boro) was evaluated at three locations (Freeville, NY; Riverhead, NY; and Monmouth, ME), for two planting dates and over 2 years (2017 and 2018), resulting in a total of 10 experiments. Tarps were applied for three durations before projected planting dates: 1) 10+ weeks (long), 2) 6 to 8 weeks (mid), and 3) 3 to 5 weeks (short), then compared with an untarped control (none). Three levels of tillage intensity were applied after tarp removal: 1) 10 to 20 cm (conventional till), 2) 3 to 8 cm (reduced till), and 3) left undisturbed (no till), to understand interactions between tillage intensity and tarping. Tarp use of three or more weeks lowered weed biomass for several weeks after beet planting and at-harvest across most locations and years, but tarp duration beyond 3 weeks did not result in further reductions. Tarp use lowered at-harvest weed biomass and increased crop yield for reduced- and no-till systems with results similar to conventional-till. Tarping for 3 weeks could improve the viability of reduced- and no-till approaches for organic vegetable production.

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Despite these benefits, reduced-till in organic systems often results in lower crop yields compared with organic conventional-till systems (Halde et al., 2015; Leavitt et al., 2011), and weed management is a primary challenge constraining reduced-till adoption by organic farmers (Lowry and Brainard, 2017). Weed density and biomass are commonly higher in reduced-till systems than in conventional-till systems (Campiglia et al., 2018; Cavalaris and Gemtos, 2002; Nakamoto et al., 2006). Although conventional farmers may increase use of herbicides when reducing tillage (Buhler et al., 1994), organic farmers primarily rely on cultivation and need more alternatives for improving weed management.

Reduced-till systems can be particularly challenging for direct-seeded root crops, such as beets (*Beta vulgaris* L.), for which farmers often rely on a fine, residue-free seedbed for planting. Beets are also poor competitors with weeds when they first emerge, and early-season weed control is crucial for a successful crop. Sugar beet yield is often decreased in reduced-till compared with conventional-till systems (Cavalaris and Gemtos, 2002; Koch et al., 2009); however, others have documented that yields can be similar between the two tillage approaches (Van den Putte et al., 2010). To our knowledge, no studies have evaluated organic table beet performance in reduced-till systems.

The application of temporary, impermeable, black plastic tarps to the soil surface before cash crop planting is an alternative weed management strategy recently popularized (Fortier, 2014), and adopted by some organic vegetable farmers (Rylander and Raucher, 2019). Tarps are durable, opaque, 0.15-mm (5- to 6-mil) polyethylene plastic applied to multiple crop rows at a time. Farmers can apply and remove tarps multiple times in a season and use them for several years. This practice is in contrast to well-studied black plastic mulch films (Abu-Gharbieh et al., 1988), which remain in place during crop growth, and to solarization with temporary placement of transparent plastic sheets on the soil at times of intense sunlight and warm temperatures. Solarization can reduce weed pressure and increase yields in numerous crops (Candido et al., 2011; Egley, 1983; Kanaan et al., 2018; Khan et al., 2012; Linke, 1994; Samtani et al., 2017); to be effective, soil temperatures must reach 40 to 65 °C to kill weeds, weed seeds, and other pests (Abu-Gharbieh et al., 1988; Egley, 1983; Öz, 2018).

Tarps may reduce reliance on tillage by providing a number of similar services. Tarps applied for 3 weeks suppress weeds before crop planting and create a weed-free seedbed in which to plant (Birthisel, 2018; Lounsbury et al., 2018; Rylander et al., 2020). Tarps also have the potential to promote fatal germination of some weeds by blocking light from emerged seedlings, but this may depend on other management factors, including the duration and timing of tarp use and soil disturbance before tarp application. The effect of

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 tillage 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 increased organic matter, nutrient retention, and biological activity compared with tilled soils (Beare et al., 1997; Franzluebbers, 2002; Gupta and Germida, 1988; Hungria et al., 2009; Tebrügge and Düring, 1999).

tarps on weed seeds is also likely species specific. Although tarps have shown no effect on *Chenopodium album* L. seed germination and degradation, survival of *Amaranthus powellii* S. Wats. seeds in the top 1 cm of soil can be higher under tarped compared with untarped soil, indicating a lower germination and degradation rate under tarps (Rylander et al., 2020).

Earlier results from this experiment, presented in Rylander et al. (2020), found tarping can create a soil environment favorable for crop planting by increasing soil moisture, temperature, and soil nitrate, while decreasing weeds by 95% to 100% at planting time without soil disturbance. Three weeks of tarp duration was adequate to achieve differences compared with untarped controls. The following research investigated the effect of black plastic tarp durations on weeds and yields of a direct-seeded beet crop and compared three levels of tillage intensity after tarp removal. We hypothesized that 1) tarping would lower weed density and biomass during beet crop growth, 2) tarping would increase beet crop yield, 3) differences in tarped and untarped soils would be greatest within no-till systems, and 4) longer tarp durations would have a greater effect on these responses.

Materials and Methods

Experiments were conducted in three locations (Freeville, NY; Monmouth, ME; and Riverhead, NY) in 2017 and 2018. Untarped control treatments (none) were compared with three tarping durations: 3 to 5 weeks (short), 6 to 8 weeks (mid), or 10+ weeks (long). Tarps were applied for each duration before two target planting dates in Freeville and Monmouth, and one planting date in Riverhead. Different fields were used in 2017 and 2018. In Freeville and Monmouth, two adjacent experiments were established for each planting date in the same field, P1 and P2 (Table 1). Combining sites, years, and planting dates, we established 10 experiments overall.

Three tillage treatments were applied after tarp removal: 1) no till (planter disturbance only), 2) reduced till (3- to 8-cm soil depth), and 3) conventional till (10- to 20-cm soil depth). In 2018, no-till/no-tarp treatments were mowed in all locations before planting to account for only newly emerged

weeds post-tarp removal in weed biomass evaluation. In all locations, beets (*Beta vulgaris* cv. Boro) (Bejo Seeds, Oceana, CA) were direct seeded across all treatments. In 2018, beets were thinned to a maximum of 15 plants per 31 cm row length 24 d after planting to not exceed recommended planting densities. Beets were not thinned in 2017.

Experimental design

Freeville, NY. Research was conducted in a certified organic field at the Cornell University Homer C. Thompson Vegetable Research Farm in Freeville, NY (42.523204, -76.326472) in well-drained Howard gravelly loam soil (loamy-skeletal, mixed, active, mesic Glossic Hapludalfs). The field was drill-seeded (Kasco KED-72 Eco-Drill, Shelbyville, IA) to oats at 112 kg·ha⁻¹ on 25 Aug. 2016 and 2017. Oats were rotary mowed (2017) or flail-mowed (2018) in November before winterkill, to chop cover crop residues ahead of applying tarps.

All experiments had a randomized complete block design for treatments (tillage, tarp duration), with four replications (blocks) consisting of 12 plots each. All plots were 3.7 × 3.7 m with two beds that were 1.8 m on center. Tarps were cut into 4.9 × 4.9 m pieces to cover plot edges and secured to the soil surface using sand bags.

Tarps were applied at different times to achieve three durations (short, mid, and long) before two target planting dates of beets: mid-May (P1) and mid-June (P2) (Table 1), and compared with an untarped treatment. Three tillage practices were applied after tarp removal: no till, reduced till, and conventional till. Conventional till (≈10.2 cm deep) was achieved using a 1.8-m tiller (Maschio B 180-C; DeWitt, IA). Reduced-till soil disturbance (≈3 cm deep) was created using a no-till drill with cutting discs and a cultipacker (Kasco KED-72; Shelbyville, IA). In 2017, no-till treatments in Freeville were not planted or cultivated due to high weed populations.

A pelletized chicken manure compost 5N-1.7P-2.5K (Kreher Family Farms, Clarence, NY) was broadcast-applied at 56 kg·ha⁻¹ nitrogen to all treatments before tillage and planting. Beets were seeded at 14.6 kg·ha⁻¹ for a plant population of 33 seeds/m (7.2 × 10⁵ seeds/ha) using a vacuum seeder (Monosem MS 4-Row Planter; Edwardsville,

KS) with four rows per bed at 38 cm between-row spacing.

Beds of all treatments were cultivated between-row only at ≈10 and 20 d after planting using a tractor cultivator (Saukville 2001 DDL; Newburg, WI) with standard beet knives (Empire USA S1122R; Cortland, NY).

Monmouth, ME. Research was conducted in a noncertified but organically managed field at the University of Maine Agricultural and Forestry Experiment Station: Highmoor Farm in Monmouth, ME (44.231993, -70.071939) in a Woodbridge fine sandy loam (coarse-loamy, mixed, active, mesic Aquic Dystrudepts). An oat cover crop was drill-seeded in mid-Aug. 2016 and 2017 at 112 kg·ha⁻¹ with a Great Plains drill (3P605NT Salina, KS). In mid-December, oats were mechanically rolled down (2017) or flail mowed (2018). Tarps were held in place by sand bags and/or burying the edges. Plots were 3 × 5.5 m encompassing three beds 1.8 m on center.

For all experiments, a split plot randomized complete block design was used with four replications (blocks) consisting of 12 plots each. Tarp durations were split by tillage treatment. Tarps were applied for the same durations before planting as Freeville (Table 1).

After tarp removal, tillage treatments were applied with a BCS two-wheeled walk-behind tractor (732GX11; Portland, OR) set at two depths: conventional till (15- to 20-cm soil depth) and reduced till (5- to 8-cm soil depth). Fifty-six kg·ha⁻¹ of nitrogen was broadcast using Pro-Gro 5N-1.7P-2.5K fertilizer (North Country Organics, Bradford, VT) before tillage and planting. 'Boro' beets were hand-seeded at 2.5 cm in-row spacing with 38 cm between rows (40 seeds/m, 1.1 × 10⁶ seeds/ha). For no-till plots, a hoe was used to create a seeding path. There was no cultivation of weeds through the season.

Riverhead, NY. Research was conducted in a non-certified but organically managed field at the Long Island Horticultural Research and Extension Center (LIHREC) in Riverhead, NY (40.962271, -72.716471) in a Haven loam soil (coarse-loamy over sandy or sandy-skeletal, mixed, active, mesic Typic). A cover crop of organic oats (89 kg·ha⁻¹) was drill-seeded (John Deer 450 Grain Drill, Moline, IL) mid-Sept. 2016 and 2017 after disking the field.

Table 1. Experiment dates for Freeville, NY; Monmouth, ME; and Riverhead, NY for two planting dates (P1 and P2) in 2 years: 2017 and 2018.

	Freeville				Monmouth				Riverhead	
	2017		2018		2017		2018		2017	2018
	P1	P2	P1	P2	P1	P2	P1	P2		
Long-duration tarp applied	15 Nov.	30 Mar.	17 Nov.	2 Apr.	8 Dec.	27 Apr.	21 Nov.	10 Apr.	19 Jan.	21 Nov.
Mid-duration tarp applied	30 Mar.	26 Apr.	2 Apr.	30 Apr.	13 Apr.	17 May	13 Apr.	21 May	11 Apr.	13 Apr.
Short-duration tarp applied	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	18 May	14 June	8 June	6 July	5 June	11 July	2 June	30 May
Beets planted	23 May	22 June	18 May	15 June	12 June	6 July	5 June	14 July	2 June	30 May
Early-season weed data	—	—	30 May	27 June	—	—	10 July	17 Aug.	—	8 June
At-harvest weed data	7 July	1 Aug.	12 July	9 Aug.	1 Aug.	19 Sept.	8 Aug.	11 Sept.	28 July	31 July
Beets harvested	25 July	15 Aug.	18 July	13 Aug.	9 Aug.	26 Sept.	8 Aug.	11 Sept.	3 Aug.	1 Aug.

The experimental design was a randomized complete block design for treatments (tillage, tarp duration), with four replications (blocks) consisting of eight plots each. Tarps were applied for three durations before the target planting date (Table 1). Two tillage treatments were applied: reduced till or no till. Reduced-till plots were prepared using a rototiller (King Kutter Inc., Winfield, AL) set at ≈ 5 cm depth. Pro-Gro 5N-1.7P-2.5K granular fertilizer (North Country Organics) was broadcast-applied to all plots at a rate of 45 kg-ha⁻¹ of nitrogen before tillage. 'Boro' beets were direct-seeded using a vacuum seeder (MaterMacc MS8100, San Vito al Tagliamento, Italy) at a rate of ≈ 49 seeds/m (1.1×10^6 seeds/ha). Drip-grape irrigation was placed in beet plots mid-June 2017 and 2018. There was no cultivation of weeds through the season.

Sampling methods at all sites

Weed assessment. Early-season weed biomass and density were assessed in 2018 (times based on location), and weed biomass at the time of beet harvest was assessed both years with times based on Table 1. Four 0.25-m² quadrats were placed over the center rows of each plot and included in-row and between-row areas. All weeds were counted, then clipped at the soil surface and weed biomass was determined by drying plant material at 60 °C for several days until constant weight, and reported on a grams per square meter basis. Weed density was reported on a plants per square meter basis.

Marketable yield assessment. At harvest, beets were collected from a 3.7-m length inner row in each plot and any attached soil was removed from roots. Whole plants (roots and tops) with a root diameter exceeding 2 cm and no blemishes were weighed as a measure of marketable yield.

Statistical analysis. Data from the two New York sites were analyzed as a randomized complete block design and for Maine as a split plot design with tarps as the main effect and tillage as the subplot. Data for all sites and planting dates were analyzed separately due to variance in management methods and significance of site in statistical

analysis. Before running statistical analysis, all data were checked for normality of residuals to meet the assumptions of analysis of variance (ANOVA). Least-squares means were compared using ANOVA using R (R Core Team, 2017) with tarp duration and tillage as fixed effects. Mean separation was by the Tukey-Kramer honestly significant difference test at 0.05 level of probability. For select weed biomass data, log transformation were applied before analysis to improve normality of residuals and were detransformed for presentation in the results.

Results

Early-season weeds. Overall, early season weed biomass in Freeville and Riverhead was small, less than 3 g-m⁻² across all treatments for both planting dates in 2018 (Table 2). Weed density ranged from 17 to 236 plants/m² in Freeville and 0 to 71 plants/m² in Riverhead (Table 2). Reduced- and conventional-till treatments decreased weed biomass in all plantings for these locations, and there were fewer and smaller weeds in conventional-till compared with reduced- and no-till treatments. Tarp use reduced weed biomass in Freeville P2, and both weed biomass and density in Riverhead P2 (Table 2). There was a significant interaction between tillage and tarping for weed density (Riverhead) and biomass (Freeville P2 and Riverhead), where tarps had a greater effect on weed density and biomass in no- and reduced-till treatments than in conventional-till treatments.

Weed biomass was much greater in Monmouth, ranging from 77 to 214 g-m⁻², and tarp use significantly reduced weed biomass (36% to 57%) in P2 but not in P1 (Table 2). Tillage treatments had no effect on weed biomass in Monmouth.

At-harvest weeds. Weed biomass at-harvest ranged from 72 to 864 g-m⁻² in no-tarp treatments and from 26 to 374 g-m⁻² in tarped treatments (Table 3). Tarp use significantly decreased at-harvest weed biomass in 6 of 10 experiments ($P < 0.01$), and there was a significant interaction between tarp and tillage treatments. In no-tarp treatments,

conventional-till significantly reduced weed biomass up to nine times compared with no-till treatments. In treatments with tarp use of any duration; however, there was no significant difference among tillage treatments (except in Monmouth P2 2018).

In 4 of 10 experiments, tarps did not decrease weed biomass, and there was no significant interaction between tarp duration and tillage. Of these four experiments, three were in Freeville, in which all measured treatments were cultivated twice during the season and data were not taken on no-till treatments in 2017.

Beet marketable yield. There was a significant interaction between tarp and tillage treatments for beet yield in four of 10 experiments (Table 4). In untarped treatments, conventional-till significantly increased yield compared with no-till (and sometimes reduced-till), but yield was similar across all tillage treatments (including no-till) when tarps were applied (Table 4). For example, in the second planting in Freeville in 2018, there was a significant interaction between tarp and tillage treatments ($P < 0.01$). When no tarp was used, yield was six times greater with conventional-till compared with reduced till and no till. In tarped treatments, there was no significant difference in yield between conventional-, reduced-, or no-till treatments.

Tarp use alone significantly increased total yield compared with untarped treatments in eight of 10 experiments, but tarp duration did not influence yield (Table 4). In contrast, conventional-till only increased yield compared with reduced or no till in four of 10 experiments (Table 4).

Discussion

One primary goal of tillage is to control weeds. As a strategy to advance reduced- and no-till production systems, it is important to understand tarp effects on weed emergence and competition with the following crop. In these studies, tarps were able to suppress weeds before planting without soil disturbance (Rylander et al., 2020). For no-till production, tarps can provide weed control similar to conventional-till both early in the season and at the time of crop harvest.

Table 2. Effect of tillage and tarp duration on early-season weed biomass (g-m⁻²) and density (counts/m²) post-tarp removal for plantings 1 (P1) and 2 (P2) in 2018 at Freeville, NY; Monmouth, ME; and Riverhead, NY.

	Freeville				Monmouth				Riverhead	
	P1		P2		P1		P2			
	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density
Tillage										
None	2 a ²	236 a	0.5 a	64 a	177	—	140	—	1 a	5 a
Reduced	0.8 ab	162 ab	0.4 b	66 a	199	—	109	—	0 b	32 b
Conventional	0.3 b	93 b	0.1 b	17 b	173	—	92	—	—	—
P value	***	***	***	***	NS	—	NS	—	*	***
Tarp duration										
None	1	110	0.7 a	33	191	—	180 a	—	3 a	71 a
Short	1	186	0.2 b	58	171	—	115 b	—	0 b	0 b
Mid	0.7	179	0.2 b	47	154	—	84 b	—	0 b	0 b
Long	0.7	181	0.2 b	58	214	—	77 b	—	0 b	2 b
P value	NS	NS	***	NS	NS	—	***	—	**	***
Interaction	NS	NS	*	NS	NS	—	NS	—	**	***

²Mean separation by Tukey honestly significant difference at $P \leq 0.05$.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Effect of tillage and tarp duration on at-harvest weed biomass ($\text{g}\cdot\text{m}^{-2}$) for Plantings 1 (P1) and 2 (P2) in 2017 and 2018 at Freeville, NY; Monmouth, ME; and Riverhead, NY.

Tr duration	TI	Freeville ^z				Monmouth				Riverhead	
		2017		2018		2017		2018		2017	2018
		P1	P2	P1	P2	P1	P2	P1	P2		
None	None	—	—	144	281 a	740 a	864 a	519 a	666 a	571 a	276 a
	Reduced	121	409 a ^y	134	253 a	243 b	331 b	95 b	310 b	260 b	136 b
	Conv	88	103 b	97	72 b	82 c	249 b	92 b	328 b	—	—
	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	NS
	Tr	NS	NS	***	NS	***	***	***	***	**	NS
	TI	NS	NS	*	**	***	**	***	NS	NS	NS
	Tr $\times$ TI	NS	NS	***	NS	***	***	***	***	***	NS

^zTreatments in Freeville, NY, were cultivated twice during the season.

^yMean separation by Tukey's honestly significant difference at $P \leq 0.05$.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Conv = conventional; TI = till; Tr = tarp.

Table 4. Effect of tillage and tarp duration on fresh beet weight (roots and tops) in $\text{kg}\cdot\text{m}^{-2}$ for plantings 1 (P1) and 2 (P2) in 2017 and 2018 at Freeville, NY; Monmouth, ME; and Riverhead, NY.

Tr (weeks)	TI	Freeville				Monmouth				Riverhead	
		2017		2018		2017		2018		2017	2018
		P1	P2	P1	P2	P1	P2	P1	P2		
None	None	—	—	0 b	0.3 b	0	0 b	0 b	0	0	0.1
	Reduced	2.6	0 b ^z	0.5 b	0.3 b	0.7	3.1 a	1.2 ab	0.1	0.5	1.1
	Conv	3.7	1.7 a	2.3 a	1.9 a	1.6	4.0 a	2.4 a	0.3	—	—
	P value	NS	**	***	***	NS	*	***	NS	NS	NS
Short	None	—	—	1.4 b	2.0	2.6	4.8	1.6	0.8	0.3	0.7
	Reduced	3.9	3.0	1.8 ab	2.2	2.2	5.7	2.3	0.6	0.6	1.0
	Conv	3.9	3.3	2.3 a	1.9	2.2	5.8	2.5	0.7	—	—
	P value	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Mid	None	—	—	1.4 b	1.6	2.2	4.5	1.3	1.0	0.6	0.8
	Reduced	3.7	2.7	1.8 ab	1.9	2.3	5.0	1.5	1.0	1.0	1.5
	Conv	3.8	2.7	2.3 a	1.7	2.7	4.3	2.1	1.3	—	—
	P value	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Long	None	—	—	2.2 b	1.1	3.0	7.6	1.8	0.6	0.7	1.3
	Reduced	4.7	3.4	2.0 b	1.9	3.1	6.8	1.9	0.8	1.1	1.7
	Conv	4.6	3.2	3.0 a	1.4	3.2	6.1	2.5	0.8	—	—
	P value	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
	Tr	**	***	***	***	***	***	*	***	NS	NS
	TI	NS	NS	***	*	NS	NS	***	NS	NS	NS
	Tr $\times$ TI	NS	*	*	**	NS	*	NS	NS	NS	NS

^zMean separation by Tukey honestly significant difference at $P \leq 0.05$.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Conv = conventional; TI = till; Tr = tarp.

At the time of tarp application for early planting dates (P1) in Freeville and Monmouth (Table 1), no summer annual weeds had emerged for any treatment (Rylander et al., 2020), and cool soil temperatures likely delayed germination and emergence until after tarp removal. Most summer annuals in the northeastern United States germinate as

soon as the soil warms (May or June), which was the time of tarp removal for the first beet planting in Freeville and Monmouth. By extending the early season weed-free period, tarps support improved germination conditions for direct-seeded crops like beets. For P2, short duration tarps were laid over emerged early-season weeds, primarily the

winter annual, *Stellaria media* L., killing them before tarp removal. This suppression of winter annuals likely contributed to a decrease in early-season weed biomass.

In these experimental locations, nitrate concentrations were higher under tarps compared with uncovered soil at tarp removal (Rylander et al., 2020). Small-seeded weed

species are generally responsive to increases in soil nutrients, such as nitrate, potentially breaking dormancy and germinating (Benecch-Arnold et al., 2000). Tarps did not, however, increase the seed germination or degradation of two small-seeded weed species, *C. album* and *A. powellii* (Rylander et al., 2020). It is unknown what effect tarps would have on germination of other weed species.

The most abundant early-season weed species across locations were *S. media*, *Amaranthus* spp., *C. album*, *Digitaria* spp., *Portulaca oleracea* L., and *Veronica persica* Poir. The most abundant weed species at harvest were summer annuals, such as *Amaranthus* spp., *C. album*, and annual grasses in Freeville and Monmouth, and *Rorippa palustris* L., *Matricaria discoidea* DC., and *Cerastium* spp. in Riverhead. For these weeds, there was no advantage to tarping longer than 3 weeks. Some perennials, such as *Cyperus esculentus* L., *Plantago major* L., *Rumex* spp., and *Taraxacum officinale* L., were present in small numbers in both tarped and untarped plots, but the effect of tarps on perennial weed species is unknown.

Tarps can help facilitate reduced- and no-till systems by improving weed control through the time of harvest. When reduced-till and no-till treatments were paired with tarp use, at-harvest weed pressure was comparable to conventional-till treatments with no tarp. In a New Hampshire study, tarps decreased weed biomass at harvest but had a significant interaction with roller-crimper date (Lounsbury et al., 2018). Specific tarp-weed interactions may vary by region and farm, depending on climactic conditions, weed community, tillage method, and presence of cover crop residue.

Beet yield in no-till and reduced-till treatments was comparable to that of conventional-till treatments when tarps were used (Table 4). There was a significant correlation between yield and weed biomass at-harvest ($R^2 = 0.2-0.6$, $P < 0.01$), and tarp suppression of weeds supported increased yields in all treatments, and similar yields among no-, reduced-, and conventional-till treatments.

Cover crop residue in tarped no-till plots did not significantly interfere with planting operations or crop establishment, likely because planting occurred 5 or more months after the termination of the oat cover crop, and residues had begun to break down. Living weeds in untarped no-till plots were likely a primary factor in decreasing crop establishment, contributing to lower stand counts and yields in these treatments.

Crop yield also may have been affected by nitrate concentrations in the soil. Soil nitrate concentrations were up to 21 times higher in tarped treatments than in untarped treatments at the time of tarp removal (Rylander et al., 2020). There was a significant positive correlation between soil nitrate concentrations at tarp removal and beet yield in six of eight experiments where nitrate was sampled ($R^2 = 0.3-0.8$, $P < 0.05$). Plots were fertilized with nitrogen before planting, which may have

masked any yield and at-harvest weed biomass differences caused by tarping effects on soil nitrate alone. The effect of increased soil nitrate concentrations in tarped treatments on yield and at-harvest weed biomass is not clear. It is possible that tarp use could decrease weeds at planting, but higher nitrate concentrations in mid- and long-duration tarp treatments could increase the growth of weeds that germinate after tarping.

Conclusions

Tarp use of 3 or more weeks may facilitate reduced tillage in organic vegetable systems by suppressing early-season weeds and increasing crop yield. Tarps retained lower weed pressure several weeks after tarp removal, decreasing competition during the critical first few weeks of beet growth. Beet yield increased in all tarped treatments compared with untarped treatments, likely due to increased weed suppression.

Tarp use decreased the difference among no-till, reduced-till, and conventional-till treatments for both at-harvest weed biomass and crop yield. This suggests that farmers could use tarps within conservation tillage strategies in organic vegetable systems and obtain comparable yields in reduced-till and no-till systems as in conventional-till systems. Increasing tarp duration more than 3 weeks did not have a significant effect on weed suppression or beet yield. Farmers therefore retain more flexibility in their farm management plans by using tarps for shorter periods of time. Using tarps before planting a cash crop can help control early-season weeds and reduce the number of tillage passes before planting.

Further research on the effects of tillage before tarping and the response of different crop and weed species to tarping would further our understanding of how tarps can be effectively used in organic vegetable cropping systems.

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