Evaluating Soil Temperature, Moisture and Greenhouse Gas Fluxes Among Reduced Tillage Practices for Organic Vegetable Crop Production

Alex Hulstrom[1-2], Matthew Van Grinsven[1], Emma Lemerand[1-2], Calli Tomasoski[2] , Laura Brosius[3], James DeDecker[2]

[1]Northern Michigan University, [2]Michigan State University Upper Peninsula Research and Extension Center, [3]Full Plate Farm

Introduction

Reduced tillage methods, including tarping, have emerged as "climate-smart" solutions for organic farming, but limited research has been conducted to examine the influence of these practices on greenhouse gas emissions and climate resilience in vegetable production systems. Our multi-year study investigated the effects of five different cover crop termination and bed preparation methods commonly used in organic vegetable production on soil temperature, soil moisture and greenhouse gas emissions in a pea-oat cover crop followed by beet, broccoli and cabbage cash crops. Our goal was to provide organic farmers in the Midwest U.S. with practical guidance for reduced tillage to support climate change mitigation and resilience.

Methods

Two diversified vegetable farms using organic practices participated in the study, including Michigan State University's Upper Penninsula Research and Extension Center (MSU-UPREC) in Chatham, MI and Full Plate Farm (FPF) in Skandia, MI. The MSU-UPREC study area consists of Ensign sandy-loam soil and FPF consists of the Shoepac sandy-loam soil series.

A fully randomized block design containing four replicates of five treatments was used at each farm, including: i) mow-till, ii) strip-till, iii) roll-crimp, iv) woven-tarp, and v) poly-tarp (n=8). A pea (100 lbs. ac^{-1}) and oat (128 lbs. ac^{-1}) cover crop was broadcast seeded in May each year, then terminated by our treatments on July 8th, 2024 and June 25th, 2025. Tarps were in-place for approximately 3 weeks before single rows of beet and cabbage (2024), or broccoli and cabbage (2025) were transplanted into each plot and fertilized with Morgan's Safe Green Lawn (10-0-4).

Soil temperature (°F) and moisture (%) observations were recorded at 1-hr intervals (HOBO MX2307), and soil CO_2 & N_2O flux observations (LICOR 7810 & 7820; mg m^{-2} d^{-1}) were collected manually from 2-collars in each plot for the duration of the study period. The SPAW Soil Water Characteristics Model was used to estimate field capacity & wilting point (in ft^{-1}) derived from soil texture and organic matter (%) lab results.

Linear mixed-effects models were used to estimate means during pre- and post-treatment periods for all response variables, and the Tukey method was used for all pairwise mean comparisons (a = 0.05) in R.

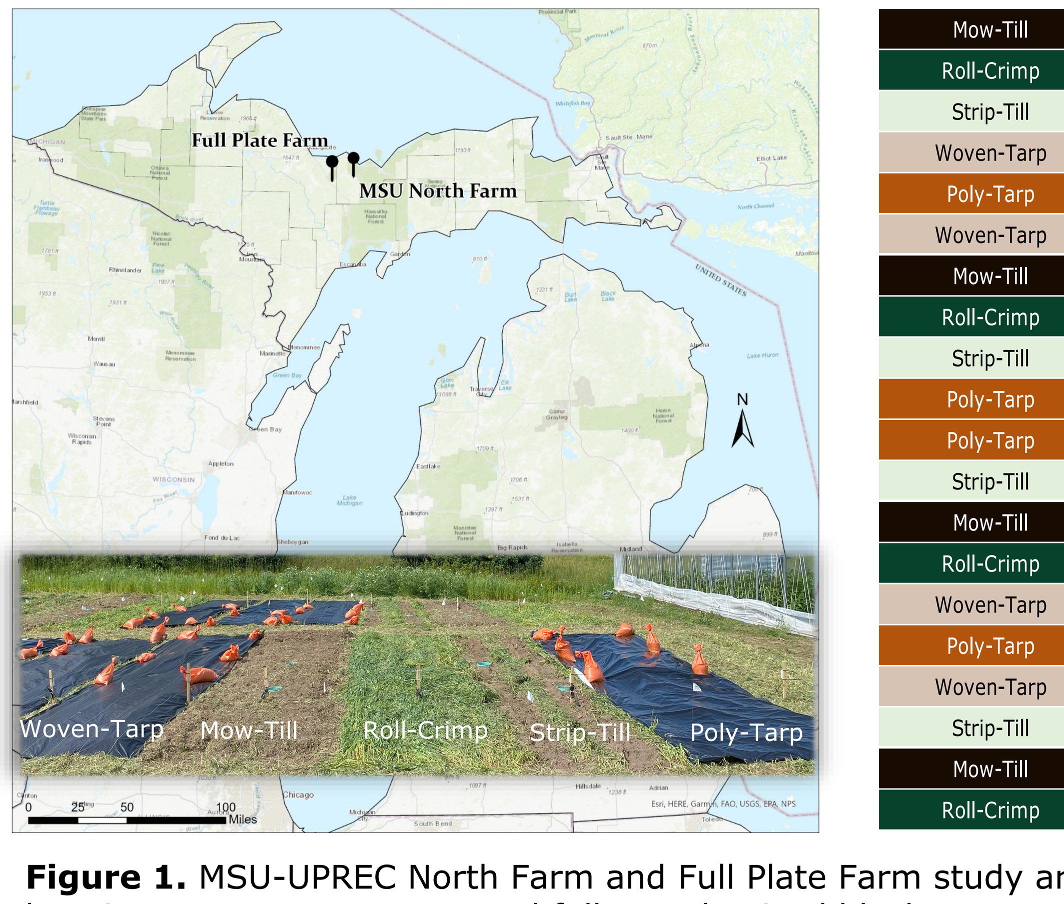

Figure 1. MSU-UPREC North Farm and Full Plate Farm study area locations, treatment types, and fully-randomized block experimental study design.

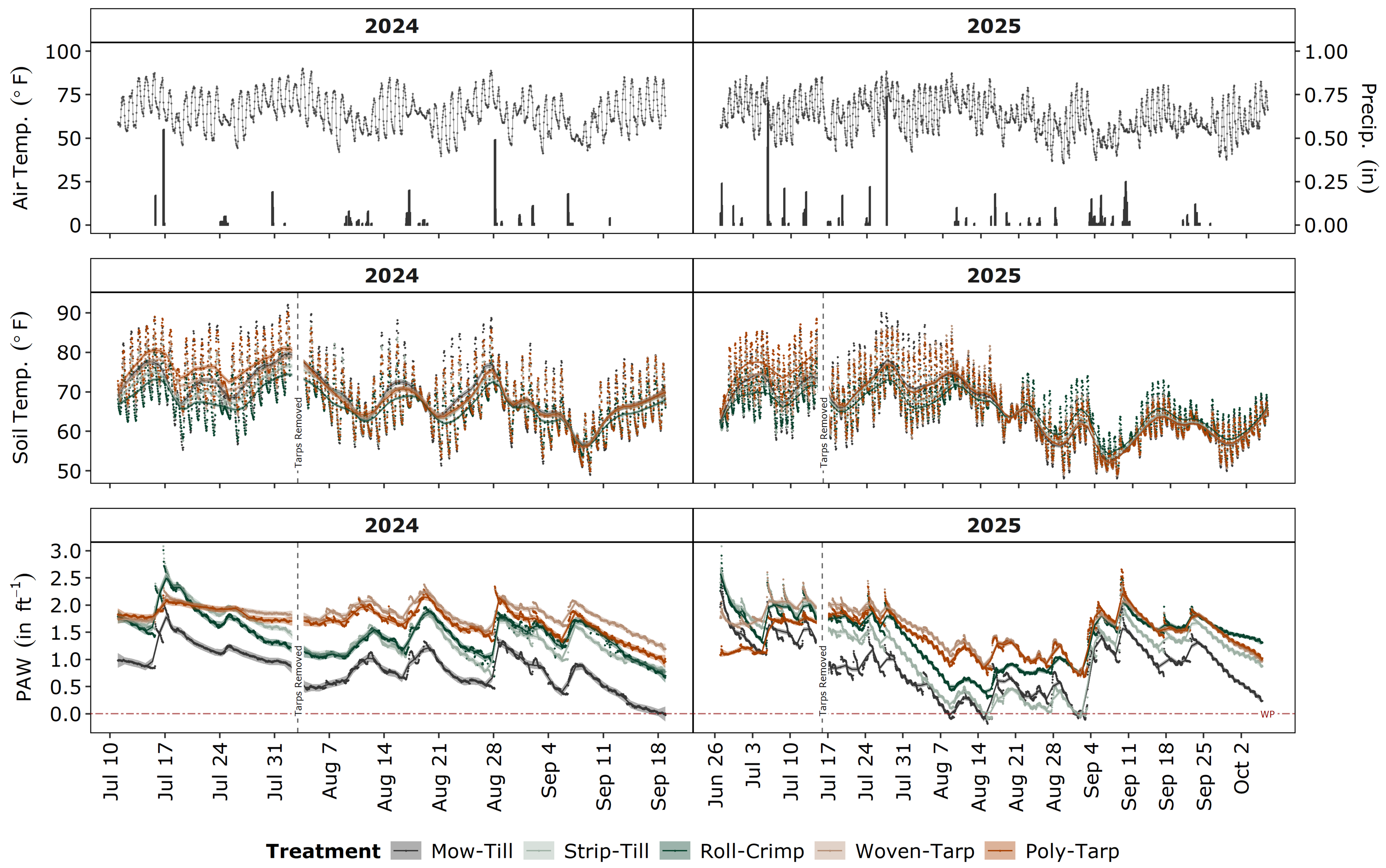

Figure 2. Hourly recorded air temperature (line; °F) and precipitation (bar; in) at MSU-UPREC (top), mean hourly soil temperature (°F) observations (points; middle) and mean hourly plant available water (in ft^{-1}) estimates (points; bottom) with loess smoothing (lines ±SE ribbons) for each treatment across farms. **Plant available water (in ft^{-1}) was estimated from hourly soil moisture (%v) observations for each farm, where wilting point (WP; dashed red line) was derived for each farm from the SPAW Soil Water Characteristics Model (Saxton et al., 2006).*

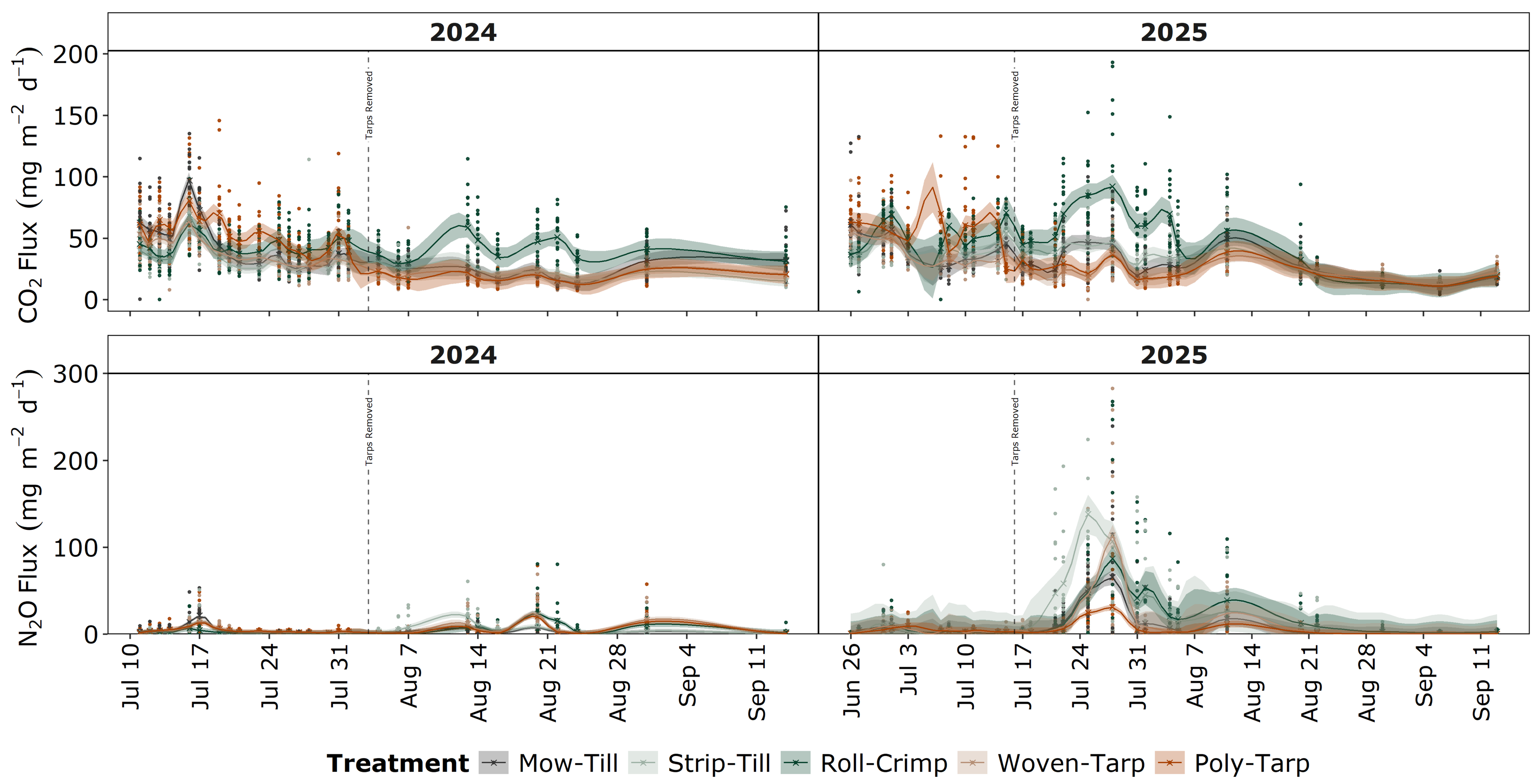

Figure 3. Daily mean soil CO_2 flux (top) and soil N_2O flux (bottom; mg m^{-2} d^{-1}) observations (points) collected from each plot (n = 8) and loess smoothing (lines ±SE ribbons) were estimated for each treatment during the pre- and post-treatment periods.

Table 1. Summary statistics including degrees of freedom (df), mean (± SE), and Tukey tests (MT; p<0.05) for soil temperature (°F), plant available water (PAW; in ft^{-1}), soil CO_2 & N_2O flux (mg m^{-2} d^{-1}) where treatment and timing (tarp-on vs. tarp-off) were used as LMM fixed-effects. **PAW, soil CO_2 and N_2O flux mean (±SE) results were back transformed for interpretation.*

Timing	Treatment	df	Soil Temp. (°F)	MT	df	PAW (In ft^{-1})	MT	df	Soil CO_2 Flux (mg m^{-2} d^{-1})	MT	df	Soil N_2O Flux (mg m^{-2} d^{-1})	MT
Tarp-On	Mow-Till	29.9	72.3 (±0.39)	a	14.1	1.3 (±0.05)	a	18.4	39.3 (±2.06)	ab	78.6	2.2 (±0.21)	a
	Strip-Till	29.9	70.7 (±0.39)	b	14.1	1.9 (±0.08)	b	17.3	35.1 (±1.81)	a	66.3	2.2 (±0.19)	a
	Roll-Crimp	32.9	68.9 (±0.40)	c	14.9	1.8 (±0.07)	c	17.8	44.5 (±2.31)	b	67.4	1.9 (±0.17)	a
	Woven-Tarp	35.2	73.3 (±0.40)	a	15.5	1.9 (±0.08)	bc	17. 6	36.8 (±1.90)	a	68.3	2.5 (±0.23)	a
	Poly-Tarp	32.7	76.1 (±0.40)	d	14.8	1.7 (±0.07)	d	21.3	54.1 (±2.93)	c	106.2	2.1 (±0.21)	a
Tarp-Off	Mow-Till	13.5	66.2 (±0.32)	a	9.3	0.8 (±0.03)	a	16.6	23.9 (±1.21)	a	61.5	2.6 (±0.23)	a
	Strip-Till	12.7	65.4 (±0.31)	bc	9.0	1.1 (±0.04)	b	17.3	26.9 (±1.38)	a	71.4	5.8 (±0.53)	b
	Roll-Crimp	13.7	64.8 (±0.32)	b	9.4	1.4 (±0.05)	c	20.9	40.4 (±2.19)	b	115.4	3.8 (±0.39)	c
	Woven-Tarp	14.0	65.7 (±0.32)	ac	9.5	1.7 (±0.06)	d	16.8	19.5 (±1.00)	c	64.7	3.1 (±0.28)	ac
	Poly-Tarp	14.2	65.7 (±0.32)	ac	9.5	1.6 (±0.06)	e	16.8	19.8 (±1.01)	c	63.5	2.3 (±0.21)	a

Results

The 76.1 mean daily soil temperature (ST; °F) under poly-tarp was significantly higher when compared to all other treatments during the tarp-on period. ST under woven-tarp (73.3) and mow-till (72.3) was statistically similar and significantly greater than strip-till (70.7) and roll-crimp (68.9). Poly-tarp, woven-tarp and mow-till treatments were significantly warmer than roll-crimp during the tarp-off crop growth period (Table 1; Figure 2).

PAW (in ft^{-1}) in mow-till was significantly lower during the tarp-on (1.3) and tarp-off (0.8) periods when compared to all other treatments. The 1.6 and 1.7 mean daily PAW (in ft^{-1}) in the poly-tarp and woven-tarp treatments were each significantly higher when compared to all other treatments during the tarp-off period (Table 1; Figure 2).

The poly-tarp 54.0 mean soil CO_2 flux (mg m^{-2} d^{-1}) was significantly larger when compared to all other treatments during the tarp-on period. However, poly-tarp (19.8) and woven-tarp (19.3) CO_2 fluxes (mg m^{-2} d^{-1}) were significantly lower when compared to all other treatments during the tarp-off period. Mean soil N_2O fluxes (mg m^{-2} d^{-1}) in mow-till, woven-tarp and poly-tarp were not significantly different from each other during the tarp-on nor the tarp-off study periods, while strip-till and roll-crimp had elevated N_2O fluxes (mg m^{-2} d^{-1}) during the tarp-off period (Table 1; Figure 3).

Discussion

Maximum daily ST in mow-till, woven-tarp and poly-tarp were on average 4.1, 1.4 and 5.2 (°F) warmer than the maximum recorded air temperature during the tarp-on study period. Mean daily poly-tarp ST was 3.8 and 2.8 (°F) warmer than the mow-till and woven-tarp treatments, respectively (Table 1).

Significantly warmer ST under poly-tarps likely contributed to the largest soil CO_2 flux, which was 37.4% and 46.7% larger than mow-till and woven-tarp treatments during the tarp-on period. Conversely, lower soil CO_2 fluxes in the poly- and woven-tarp treatments during the tarp-off period indicated that soil C was mineralized more rapidly under tarps when compared to tillage and especially roll-crimp (Table 1; Figure 4). The largest mean soil CO_2 fluxes during the tarp-off crop phase were detected in roll-crimp (Table 1) indicating delayed transformation of C from pea & oat residues.

Both woven- and poly-tarp treatments maintained more PAW, and were 0.9 and 0.8 (in ft^{-1}) greater than mow-till during crop growth. The preservation of soil structure using tarping methods has important climate resilience implications for conserving water during droughts (Table 1; Figure 2). The predominant no-till soil management history at Full Plate Farm likely contributed to the comparatively higher water content observed there, given the similarity among soil texture and organic matter content at both farms.

Organic farmers are readily adopting reduced tillage methods, especially tarping, to capture the benefits of crop/residue termination, soil moisture management, nutrient cycling and crop performance without soil disturbance and the associated costs. However, our results suggest that tarping may also increase GHG emissions from soil above levels from conventional tillage when installed. Outcomes elsewhere will therefore depend on when and how long tarps are in place. Further investigation is needed to help organic farmers reduce tillage and balance their priorities for crop production with climate change mitigation and resilience.

Acknowledgements

Support for this research was provided by Organic Valley Farmers Advocating for Organic, MSU College of Agriculture and Natural Resources - Doug and Maria Bayer New Initiatives Fund for Sustainable Agriculture and Northern Michigan University. Thank you to all NMU students and MSU-UPREC staff who contributed to this research.