Combining strip-tillage and zonal cover-cropping for soil and moisture conservation in organic vegetable systems
Final Report
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I. Project Abstract

The goal of this project was to promote soil and moisture conservation while improving nitrogen use efficiency and weed management through development of reduced tillage systems for organic vegetable growers. Specific objectives included: 1) evaluation of the potential benefits of strip-tillage (ST) and zonal cover-cropping (ZCC) for nitrogen management, soil moisture retention and weed suppression, and 2) development of integrated cultural and mechanical weed management practices for reduced tillage systems, with an emphasis on "in-row" cultivation tools including finger and torsion weeders. In 2014-16, field experiments were conducted to: 1) evaluate the impact of ST and ZCC on nitrogen use efficiency, water conservation and weed suppression in organic sweet corn, snap beans and broccoli, and 2) evaluate the efficacy and selectivity of various mechanical cultivation tools. In general, ST resulted in equivalent or higher total yields of sweet corn and snap beans relative to CT, but resulted in equivalent or lower total yields of broccoli. In sweet corn production systems, segregating rye and vetch into strips increased soil N availability in the in-row zone, but did not affect sweet corn yields or N uptake, nor did it have any detectable benefits for weed suppression. In one of two years, ST increased sweet corn yields by suppressing weed emergence and growth. However, in a second year, ST decreased sweet corn yields and resulted in significantly greater weed biomass compared to FWT. In separate studies, we evaluated the potential for in-row cultivation tools including finger, flextine and torsion weeders to manage weeds in the in-row zone, while relying on rye cover crop residue to suppress weeds in the between-row zone. In general, finger weeders were more effective than torsion weeders or flextine weeders at managing in-row weeds without damaging the crop. In some cases, combinations of tools were more effective than single tools.

II. Introduction

The goal of this project was to promote soil and moisture conservation while improving nitrogen use efficiency and weed management through development of reduced tillage systems for organic vegetable growers. Excessive tillage is a major cause of poor tilth and nutrient losses on organic farms. Additionally, tillage entails considerable fuel consumption, accelerates losses in soil organic matter and its associated functions, and promotes soil erosion. Reduced-tillage (RT) practices minimize these problems, and buffer crops from rainfall extremes by increasing soil water storage and water infiltration. Despite these potential benefits, adoption of RT systems has been constrained on organic farms because of the important role tillage plays in weed and nitrogen management; the two factors most limiting yields in organic systems (Clark et al., 1999; Barberi, 2002; Posner et al., 2008). Tillage is also important for successful establishment of many small-seeded crops.

To address these constraints and promote adoption of RT practices on organic farms, we are examining integration of strip-tillage (ST) and zonal cover cropping (ZCC) practices. Under ST management, tillage is confined to the narrow in-row zone directly in line with the crop, leaving the between-row zone undisturbed (see Fig. 1). This approach maintains tillage where it is required for crop establishment and growth, while facilitating improvements in soil health in the undisturbed BR zone.

ZCC involves targeted-planting of different cover crop species to match requirements of specific zones. For example, when low C:N cover crops (e.g. legumes) are planted in-row, and high C:N cover crops are planted between-row, nitrogen availability is targeted to crop roots, resulting in increased N uptake and decreased N losses. In ST systems, the high C:N cover crops provide a persistent mulch for weed suppression between crop rows. By combining ST and ZCC, we hypothesize that the benefits for soil health and nutrient cycling will be enhanced. Thoughtful combinations of ST and ZCC are also likely to improve system-wide water conservation, and buffer crops from weather extremes. For example, preliminary results demonstrate that rye cover crop residues retained on the soil surface increased soil moisture retention during droughts, and reduced soil splash during heavy rainfall events.

Objectives. The **<u>primary objectives</u>** of our research were to:

1) **Evaluate the impact of strip-tillage (ST) and zonal cover-cropping (ZCC) on N dynamics, soil moisture, weeds, and sweet corn yield.**

   ***Anticipated outcomes*:** We hypothesized that ST combined with ZCC of rye-vetch mixtures would improve nitrogen use efficiency, soil moisture conservation, weed suppression and crop yield compared to standard organic full-width tillage and cover cropping practices.

2) **Develop integrated weed management practices for organic reduced-tillage systems, and evaluate their impact on weeds, crops and soil health.**

   Anticipated outcomes: We anticipated that 1) the effectiveness of weed management in ST systems can equal or exceed that of CT systems with thoughtful integration of cover crop residue, stale seed bed techniques, and in-row mechanical cultivation; 2) these novel ST systems will result in long-term improvements in soil quality, moisture conservation and crop yield.

<u>III. Project Methods and Materials</u>

<u>*Objective 1. Strip tillage and zonal cover-cropping*</u>

<u>Experiment 1.1.</u> A field experiment was conducted on organically managed land at the Kellogg Biological Station (KBS) in Hickory Corners, MI. Treatments consisted of rye and hairy vetch spatial arrangement (no cover crop, mixed, or segregated—see Fig. 2) and tillage (conventional full-width tillage [FWT] vs. ST). Treatments were arranged in a RCBD with 4 replications. Cover crops were established in early September and mowed in late May or early June when hairy vetch was in midbloom in order to decrease the potential for regrowth that occurs with mechanical termination. Tillage occurred one week after mowing, and sweet corn (*Zea mays* var. Luscious) was planted on 27 June. Weed management was accomplished via flaming prior to corn emergence, and frequent hand-weeding. Soil inorganic N concentration was measured every 10-14 days, and potentially mineralizable N assays performed after tillage to evaluate the potential for N release from cover crop residues. We also measured weed emergence, biomass, N content, as well as sweet corn biomass, N content, and yield in every treatment and subplot.

Experiment 1.2. The effects of zonal cover cropping (ZCC) on vegetables were also evaluated and demonstrated at the MSU Student Organic Farm (SOF) at the Horticultural Teaching and Research Center (HTRC) in Holt, MI in 2014. ZCC treatments described above for Experiment 1.1, were duplicated at the SOF preceding ST sweet corn. Full-width rye-vetch mixtures (standard practice) were compared with ZCC using segregated strips of rye and vetch prior to sweet corn. Cover crops were mowed on 2 June; tillage occurred on 10 June; and planting occurred on 16 June. Weed management was accomplished via flaming prior to corn emergence, and hand-weeding. Sweet corn was harvested on 4 September and 15 September.

Objective 2: Integrated weed management under ST

Experiment 2.1a. Field trials were conducted during the 2014-16 on organically certified land at the HTRC to evaluate the effects of various mechanical tools (see Figure 3) for management of weeds within the crop row of strip-tilled vegetables. In 2014-15, five weed management treatments were evaluated for management of in-row weeds: 1) a Lely flextine cultivator; 2) a Garford finger weeder; 3) a Bezzerides torsion weeder; 4) a Bezzerides "Spinner" and 5) a weedy control (unweeded). The effects of these treatments were evaluated on both sweet corn and "surrogate weeds" including yellow mustard (to simulate a broadleaf weed like wild mustard) and Japanese millet (to mimic an annual grass like barnyardgrass) sown on the same day sweet corn was planted. Surrogate weeds were used to ensure more uniform density of species in cultivation plots. Immediately before and after each cultivation, both ambient and surrogate weed seedlings were counted by species in two 0.25 m^2 quadrats per plot in the crop row. Weed and crop biomass and density by species were evaluated on from two 0.25m^2 quadrats in each plot.

Experiment 2.1b. In 2016 we began testing combinations of in-row tools in various crops using a three-point steerable toolbar (Figure 4). Single tools included Torsion (Hak), Finger (Kress) and flextine (Lely) weeders. Combinations included all double and triple combinations of these tools. Evaluations were conducted in snap beans as described above. Tools were also evaluated and demonstrated at the Zilke Vegetable Farm in Sept 2016, as well as several other field days in Central and Western Michigan.

Experiment 2.2. A long-term organic field trial was conducted on organically certified land at the HTRC in Holt, MI during the 2014-16 production seasons, to examine the effects of tillage and compost on 1) crop establishment, quality and yield, 2) weed density and composition, and 3) soil characteristics. Treatments were initiated in an existing long term tillage x compost trial established in 2009 that was transitioned to organic production beginning in 2011 and fully certified in spring 2014. Experimental plots were arranged in a split- plot design with tillage as the main plot factor, compost as the subplot factor, and crop (broccoli, sweet corn of snap beans) as the sub-sub plot factor. Tillage consisted of either full-width tillage (FWT) using a rototiller, or strip tillage, accomplished using a Hiniker 6000 two-row strip-tiller equipped with row-cleaner, offset disks and a rolling basket. Weed management was accomplished using a combination of flame weeding, cultivation with a Hillside cultivator as needed between crop rows and finger weeding (Kress finger weeder) and hand-weeding as needed in the in-row zone. Weed species composition and density, soil temperature, moisture, N-dynamics and crop yield were evaluated.

IV. Results

Objective 1. Strip tillage and zonal cover-cropping. The effect of zonal cover cropping on cereal rye and hairy vetch biomass and sweet corn yield was evaluated at two sites (KBS and SOF) in 2014 as part of Carolyn Lowry's PhD thesis. Results of these studies were presented in two recent publications (Lowry and Brainard, 2016 and 2017), which provide many details beyond those presented in this report. At KBS, zonal cover cropping of cereal rye and hairy vetch resulted in no significant difference in biomass of either cover crop species compared to the standard mixed biculture. In 2014, at both KBS and the MSU student organic farm, we found no significant difference in sweet corn yield due to cover crop spatial arrangement, however at KBS, we did find that having a cover crop present increased sweet corn yield compared to the no cover crop control in 2014. This effect may have been due to greater soil moisture retention (Figure 5). However, this benefit of soil moisture retention was offset in some years by reduced soil inorganic N compared to FWT (Figure 6), and greater N losses through leaching (Figure 7).

Experiment 2.a. In-row cultivation tools. During the 2014-5 seasons, we tested a range of in-row tools on survival of sweet corn and surrogate weeds. By using surrogate weeds we were able to control the density and growth stage much more easily than relying on ambient weeds in the seedbank, which were highly variable in the field we used for this study. Surrogate weeds in this study emerged and grew more rapidly than any of the ambient weeds including species such as common lambsquarters, large crabgrass and Powell amaranth. As a result, the size differential between our surrogates and sweet corn was smaller than that of actual weeds in the field, and therefore, our results represent a "worst case scenario". Under these conditions, some sweet corn mortality occurred with all of the tools. Among the tools tested, the Finger weeder provided the most consistent weed control with selectivity indices (ratio of crop survival to weed survival) ranging from 2-8 for the mustard (broadleaf weed surrogate) and 2-5 for Japanese millet (the grass surrogate weed) (Table 1). A selectivity index of 2 implies that the tool is twice as effective on the weed compared to the crop. These results demonstrated that several of the tools we tested have greater selectivity than flextine cultivators—which are currently the most common in-row weed control tool used by organic growers. Our results also demonstrated large variation in efficacy and selectivity across runs and between weed species. These differences most likely reflect variation in soil conditions, crop-weed size differential, and the aggressiveness of tool settings. Future studies will focus on better understanding which tools are most effective under which combinations of soil, crops and weeds.

Experiment 2.1b. Combinations of in-row cultivation tools. Building on our experiences with single implements (Experiment 2.1a), in 2016 we began testing combinations of in-row tools in various crops using a three-point steerable toolbar (Figure 4). This toolbar, which we imported from a Dutch Company (with partial support from a USDA grant), provides more precise depth control and steering than was available with the belly-mounted implements used in Experiment 2.1a. This tool also allows multiple in-row tools to be "stacked" in sequence within the same row. We hypothesized that such tool stacking would improve the efficacy of mechanical cultivation. In 2016, we tested this tool in various crops including snap beans, for which initial results are presented in Table 2. Consistent with Experiment 2.1a, we found that the finger weeder had better efficacy and selectivity than the torsion or flextine weeders (Table 2). Combinations of tools generally increased weed mortality, but also sometimes increased crop mortality to unacceptable levels. Combinations involving the torsion weeder were often particularly damaging to the crop. The most impressive combination in this study was the finger + flextine combination which resulted in almost 100% suppression of weeds with minimal crop injury. Future work will continue to evaluate the conditions under which combinations of tools can improve selectivity. This work is being continued in snap beans, as well as carrots and winter squash, through several new grants that we have received based in part on the preliminary results we were able to provide through our work on this grant.

Experiment 2.2. Long-term strip tillage experiments. In our long-term strip tillage trial, we found that snap bean yields were unaffected (2016) or improved (2015) by strip tillage relative to full width tillage (Table 3). Higher yields in snap beans under strip tillage in 2015 were due at least in part to lower incidence of seed corn maggot damage which substantially reduced stand establishment in the full width tillage system. Snap beans may have also benefitted from higher soil moisture, and were not adversely affected by lower rates of N mineralization that we observed in sweet corn (Experiment 1).

In contrast with snap beans, broccoli yields were either unaffected (2015) or reduced (2014) by strip tillage (Table 3). In 2014, strip tillage resulted in 31% lower broccoli yields than full-width roto-tillage, due in part to a reduction in marketable head weight of about 18% (Table 3). The addition of compost improved broccoli yields in both FWT and ST systems, with slightly greater improvements occurring under ST. Yields of broccoli under ST with compost were equivalent to those under FWT without compost. Reductions in N availability, rather than differences in moisture or temperature were likely responsible for depressed yields of broccoli under ST. Greater weed and cover crop regrowth in the ST system, may also have contributed to lower yields.

Data analysis from this long term trial is currently being conducted, and we anticipate submitting a publication related to this work in early 2018. Results are also being presented (by Hayden) at the ASHS meeting in 2017.

V. Dissemination of Results

Results from this project have been shared with growers, extension educators and researchers through numerous venues including publications in scholarly journals (Lowry and Brainard, 2016; 2017); presentations at academic conferences (ASHS; Weed Science Society of America; European Weed Research Society) and grower meetings (Great Lakes Fruit and Vegetable Expo) and field days. We have had 2 twilight meetings at Zilke's Vegetable Farm in Milan, MI to both discuss research results and to demonstrate equipment and zonal cover cropping options to SE Michigan organic vegetable growers. We have also demonstrated our tools and ideas to certificate students at the MSU Student Organic Farm each year of the project. In 2016, we held grower field demonstrations at the Weed Science Field Day in Holt, MI, and with organic farmers at a twilight meeting in Fremont, MI.

VI. Training of graduate students and Post Docs

This funding provided important support for Carolyn Lowry's PhD thesis, which she successfully completed in spring of 2015. Dr. Lowry is currently and NIFA post-doctoral fellow at the University of New Hampshire. Partial funding also went to support Post Doc Zachary Hayden. Dr. Hayden is now an

Assistant Professor in the Department of Horticulture at MSU, and continues to be engaged in research initiated through this grant. Finally, MS student Sam Hitchcock Tilton also received support through this grant to initiate his thesis research. He was particularly involved in Experiment 2.1b, and parallel trials involving in-row weed management in carrots.

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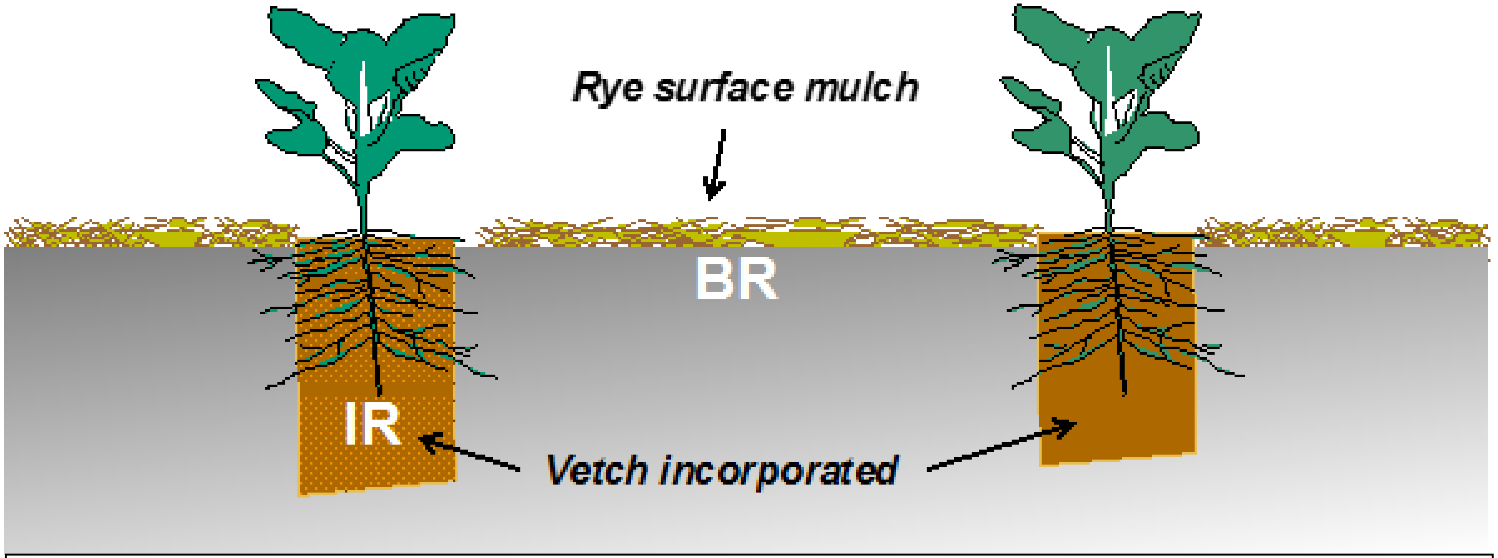

Figure 1. Strip-tillage combined with zonal cover cropping allows seedbed preparation and incorporation of high-N residue (e.g. vetch) in-row (IR), while maintaining surface cover crop mulch (e.g. rye) between-row (BR) for soil and moisture conservation and weed suppression (Adapted from Brainard et al. 2013).

Figure 2. Rye and vetch planted in segregated strips. A full width mixture can be seen in the background.

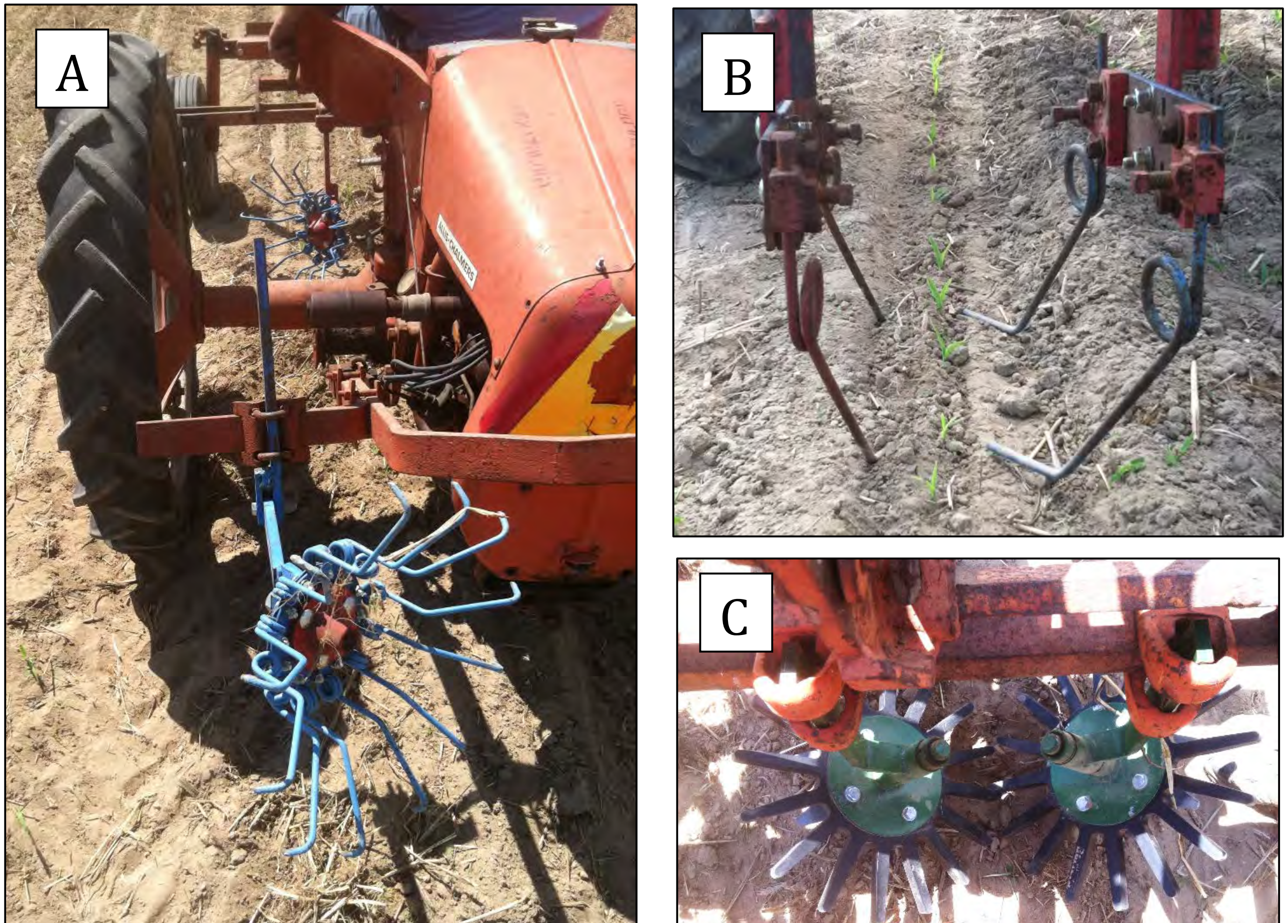

Figure 3. In-row cultivation tools evaluated in Experiment 2.1a included the Bezzerides Spinner (A), Bezzerides torsion weeder (B) and the Kress Finger weeder (C). Tools were belly-mounted on an Allis Chalmers G tractor .

<u>Figure 4</u>. In row cultivation tools evaluated in 2016 included Kress finger weeders (Right) and Torsion weeders (L) used both alone and in combination.

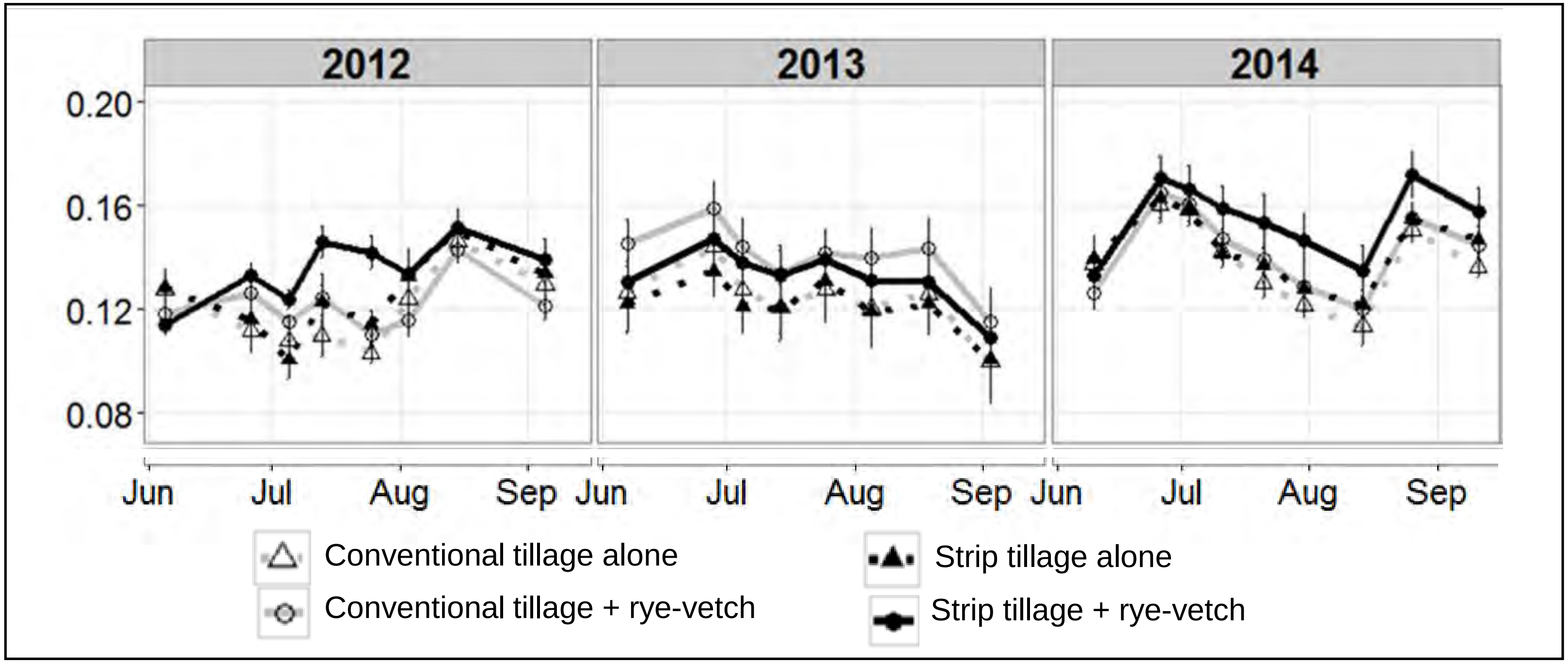

Figure 5. Effect of tillage and cover crop on gravimetric soil moisture in organic sweet corn. Strip tilled treatments had higher soil moisture in 2012 and 2014. The rye-vetch cover crop increased soil moisture compared to no cover crop treatments in all three years.

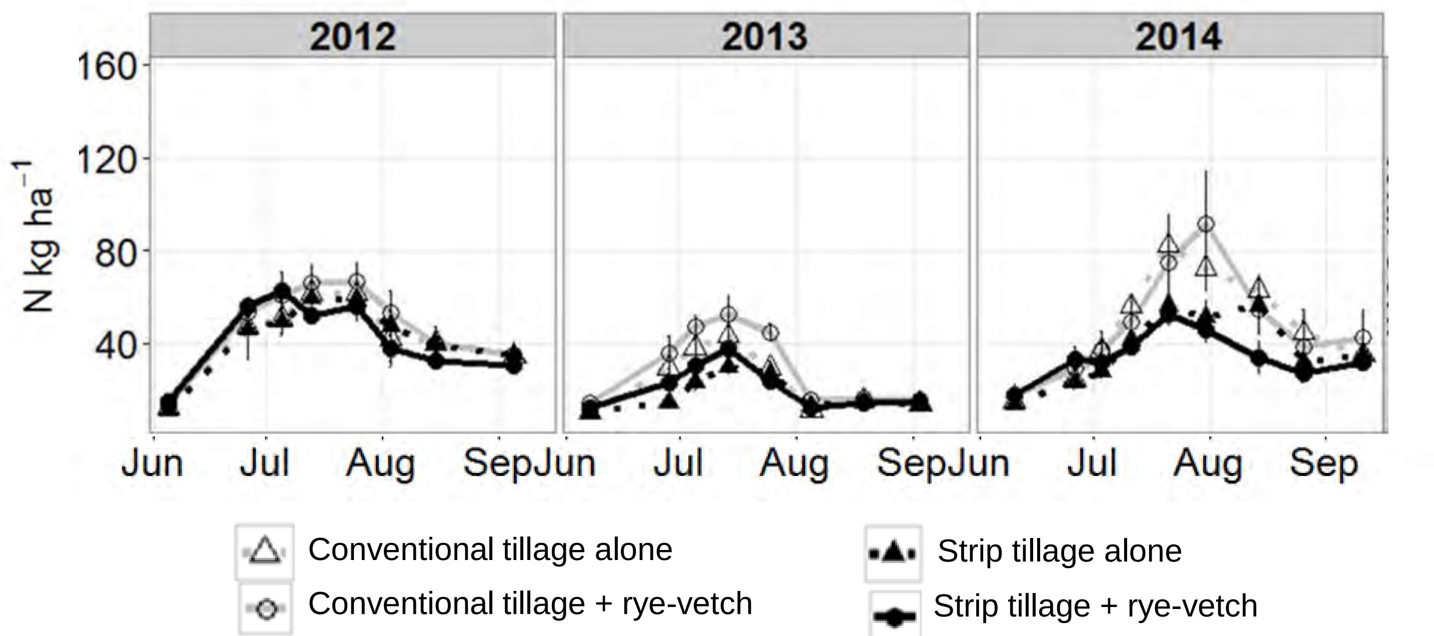

Figure 6. Effect of tillage and cover crop on soil inorganic N in organic sweet corn. Strip tilled plots had lower soil inorganic nitrogen compared to conventional tillage in all three years.

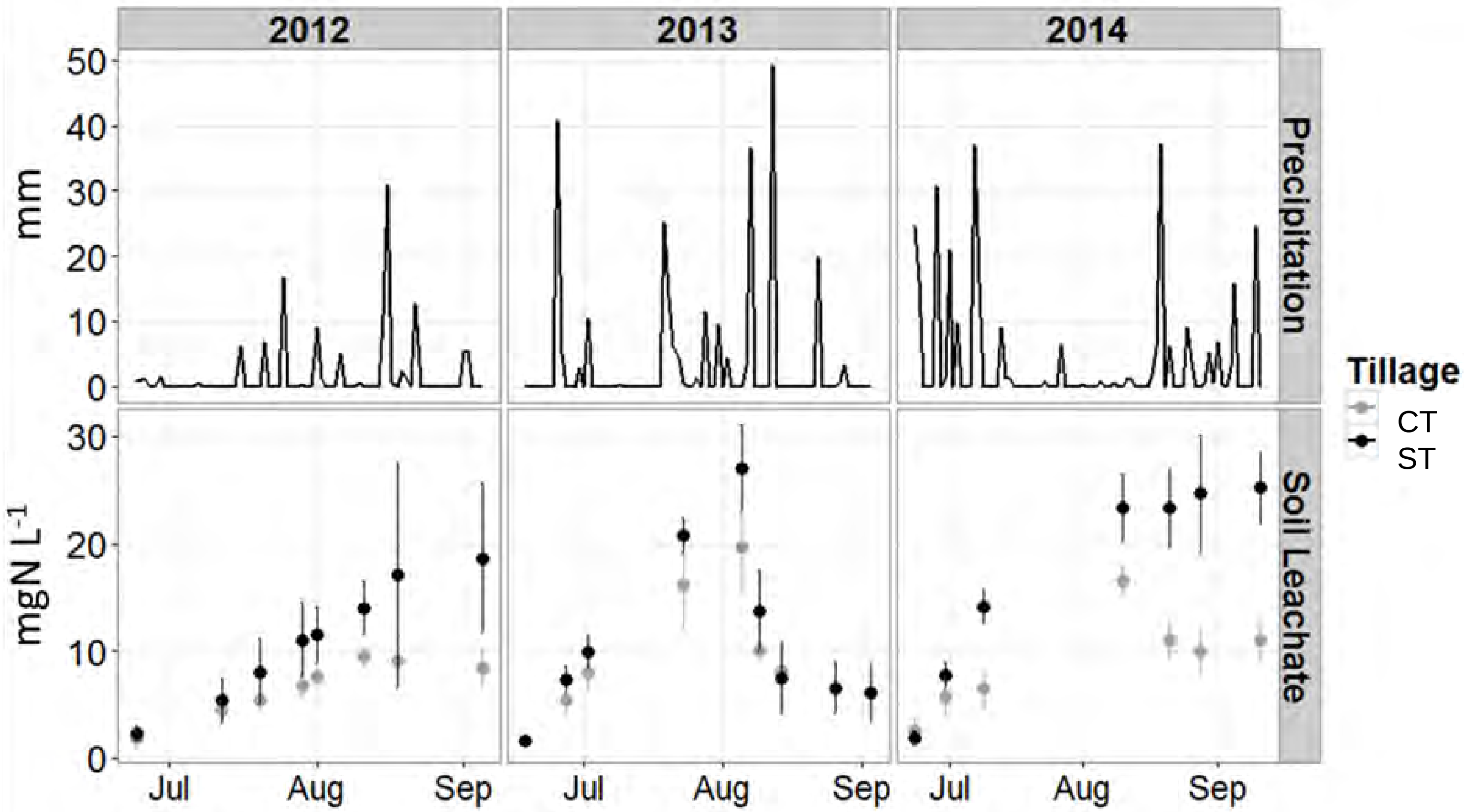

Figure 7. Effect of tillage and cover crop on nitrogen concentration in leachate collected after each major rainfall event at 1 m depth, 2012-2014. Precipitation is shown in upper panel. In all three years, N concentration was higher in strip tillage (ST) compared to conventional tillage (CT).

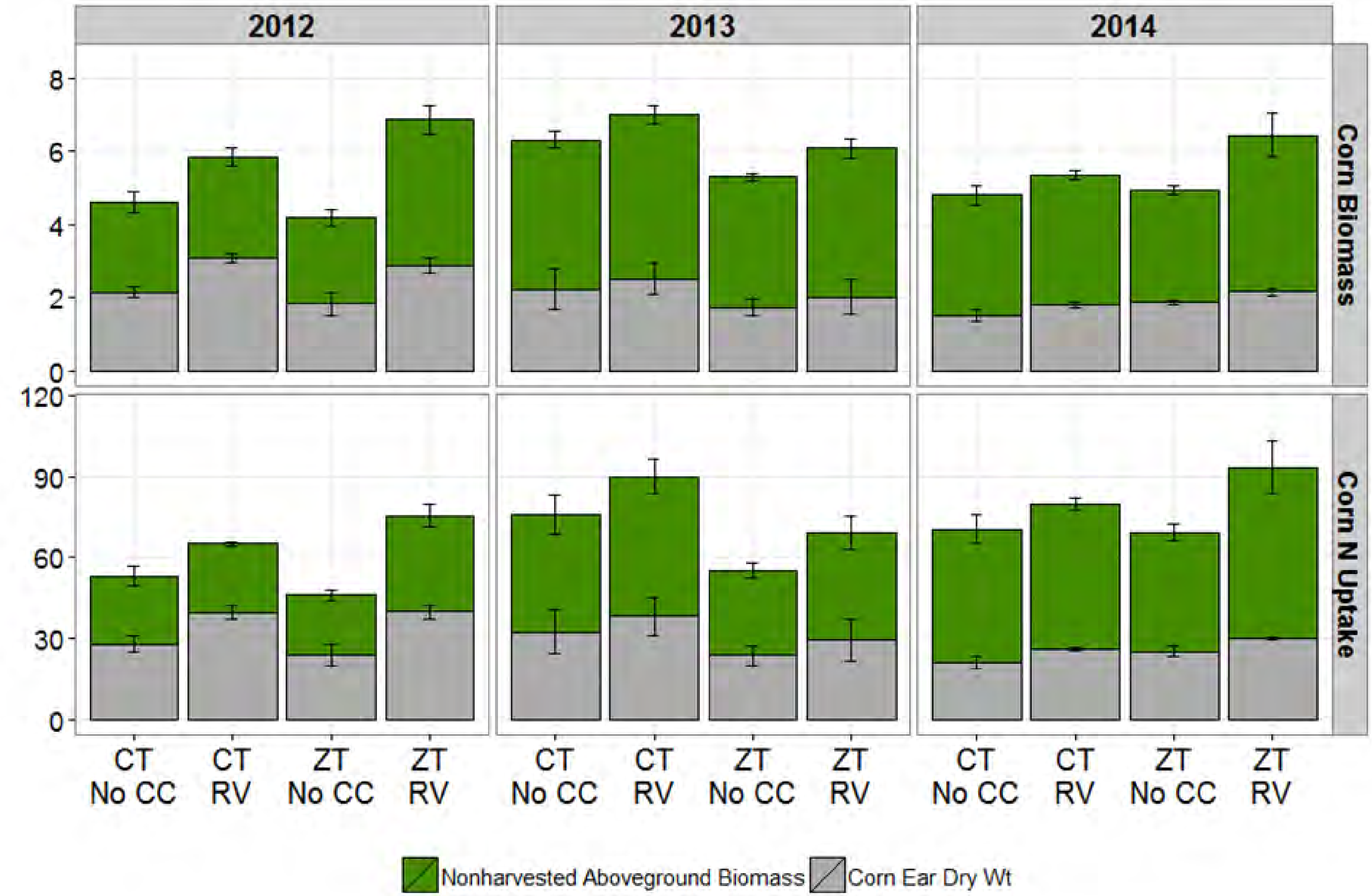

Figure 8. Effect of tillage (conventional till [CT] and strip till [ZT]) and cover cropping (rye-vetch [RV] or no cover crop [No CC]) on sweet corn biomass and nitrogen uptake, 2012-14.

Table 1. Preliminary analysis of effects of different in-row cultivation tools on survival and selectivity indices of yellow mustard, japanese millet and sweet corn, 2014 and 2015.

	Survival									Selectivity Indices[a]					
	Yellow mustard			Japanese millet			Sweet corn			Corn vs Mustard			Corn vs Millet		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
	%														
None	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	1.00 c	1.00 c	1.00 c	1.00 c	1.00 b	1.00 a
Torsion	59.5 b	67.8 b	63.4 b	47.7 b	68.2 b	59.2 b	93.8 a	90.9 ab	75.6 b	1.67 ab	1.52 b	1.14 c	3.04 bc	1.30 b	1.14 a
Flextine	39.4 c	62.2 b	55.8 b	16.7 c	47.0 c	56.9 b	72.9 b	82.2 b	77.3 b	1.44 bc	1.16 bc	4.25 b	6.61 a	2.20 ab	1.23 a
Spinner	67.0 b	61.5 b	24.3 c	44.0 b	67.1 bc	37.5 bc	85.3 ab	86.6 ab	52.5 c	1.19 bc	1.22 bc	2.11 bc	2.13 c	1.52 b	1.26 a
Flame	NA	NA	22.5 c	NA	NA	35.0 bc	NA	NA	73.2 bc	NA	NA	11.43 a	NA	NA	1.76 a
Finger	55.9 bc	54.5 b	4.9 c	30.5 bc	50.6 bc	12.7 c	89.9 a	97.1 ab	37.3 c	2.07 a	2.02 a	8.88 ab	5.48 ab	2.37 a	2.12 a

[a] Selectivity indices were calculated by dividing survival of sweet corn by survival of either yellow mustard or japanese millet.

Table 2. Impact of in-row cultivation tools and tool combinations on survival of weeds and snap beans, 2016.

	Survival (%)							
	AMAPO		CHEAL		DIGSA		Beans	
Torsion (T)	39	bc	18	bc	18	b	94	ab
Finger (F)	5	cd	18	bc	2	b	108	a
Flextine (X)	51	b	34	b	72	a	98	a
T+F	0	d	0	c	0	b	60	c
T+X	5	cd	0	c	2	b	61	c
F+X	0	d	0	c	0	b	97	a
T+F+X	14	bcd	2	bc	1	b	67	c
None	100	a	100	a	100	a	100	a

Codes: AMAPO = Powell amaranth; CHEAL = Common lambsquarters; DIGSA = large crabgrass

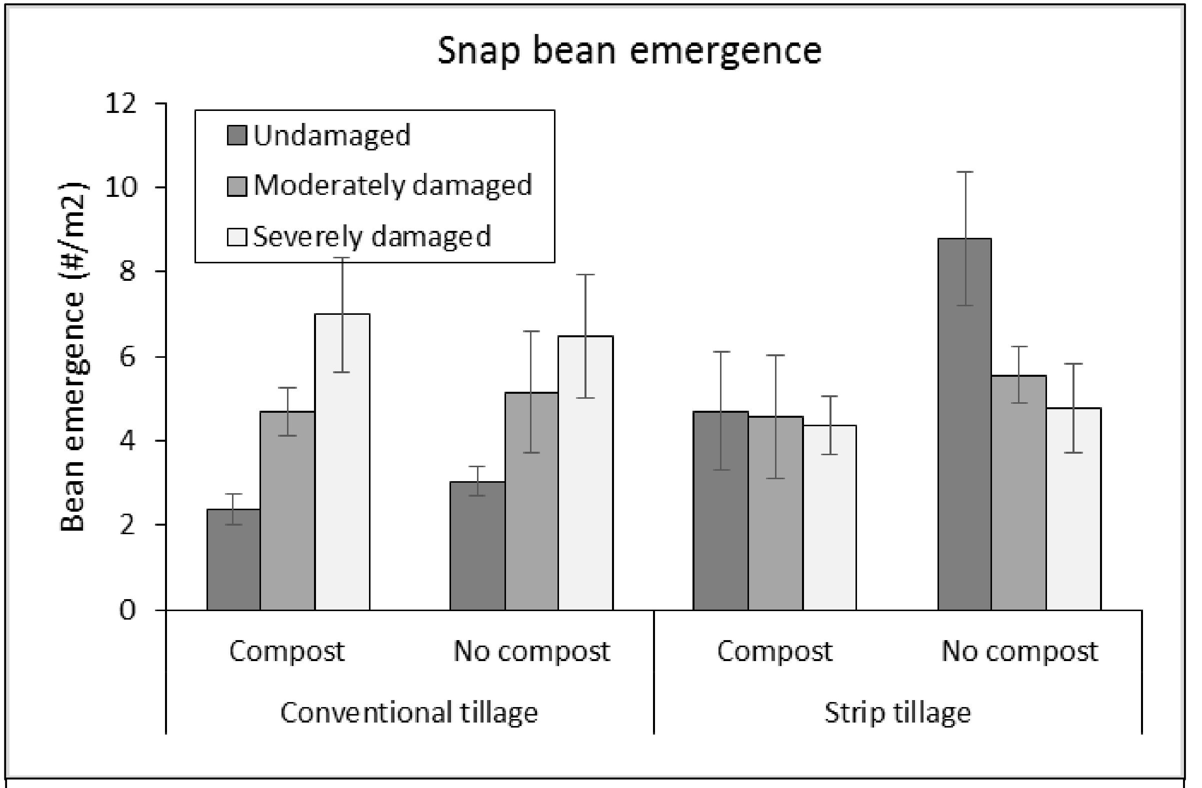

Figure 9. Effect of tillage and compost on snap bean emergence, and damage due to seedcorn maggot, 2015. Seedcorn maggot damage was lower in strip tillage compared to conventional tillage treatments, and higher in compost compared to no-compost treatments.

Table 3. Tillage and compost effects on bean plant fresh weight, harvest index, final plant number and weight per plant, 2015 and 2016.

	Plant fresh weight							
	Pods (Yield)		Shoot		Total		Harvest Index	
	2015	2016	2015	2016	2015	2016	2015	2016
	---kg/ha---							
Tillage main effects								
Conventional tillage	4,853 b	7,879	7,277	12,558	12,130	20,438	0.40 (b)	0.39
Strip tillage	6,565 a	9,587	6,689	12,933	13,253	22,520	0.49 (a)	0.42
Compost main effects								
Compost	5,728	8,706	7,970 A	14,888 A	13,698 A	23,594 (A)	0.41 (b)	0.37
No compost	5,690	8,759	5,995 B	10,603 B	11,686 B	19,363 (B)	0.48 (a)	0.45
Tillage x compost interactive effects								
Conventional tillage								
Compost	4,932	6,950	8,662	15,650	13,595	22,600	0.35	0.31
No compost	4,774	8,808	5,892	9,467	10,666	18,276	0.45	0.48
Strip tillage								
Compost	6,523	10,463	7,279	14,126	13,801	24,589	0.47	0.42
No compost	6,607	8,710	6,099	11,740	12,705	20,450	0.52	0.42
ANOVA Significance of Fixed Effects (P-value)								
Tillage	0.023	NS	NS	NS	NS	NS	0.068	NS
Compost	NS	NS	0.002	0.028	0.029	0.074	0.072	NS
Tillage x Compost	NS	NS	NS	NS	NS	NS	NS	NS

[a]Harvest index was calculated on fresh weight basis as pod weight divided by total weight.
Within each main effect, different letters indicate significant difference at 0.05 probabiliy level; letters in parentheses indicate signficant difference at 0.10 level.

Table 4. Impact of tillage and compost on broccoli yields, 2014-15

	2014	2015
	-----------kg/plot-----------	
Tillage main effects		
Conventional tillage	**13.70 a**	20.14
Strip tillage	**9.50 b**	17.24
Compost main effects		
Compost	**13.80 a**	20.36
No compost	**9.50 b**	17.02
Tillage x compost interactive effects		
Conventional tillage		
Compost	16.10	**23.64 a**
No compost	11.30	**16.65 b**
Strip tillage		
Compost	11.40	**17.09 b**
No compost	7.60	**17.38 b**
ANOVA Significance of Fixed Effects (P-value)		
Tillage	**< 0.001**	NS
Compost	**0.008**	NS
Tillage x Compost	NS	**0.091**