

Ceres Trust Graduate Student Grant **Annual Report**

Project title: Overcoming barriers to consistent yields in reduced tillage organic vegetable production

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Amount awarded by Ceres: \$9,982

Abstract

Organic no-till and strip-till systems have gained attention because of their capacity to enhance soil health and suppress annual weeds. This study, conducted at the Horticulture Research Station, Ames, IA, compared no tillage (NT), strip tillage (ST), and conventional tillage (CT) in organic production of broccoli and bell pepper, with data being collected on crop yield, plant health, weed suppression, soil growing degree days, nitrate leaching, and production system economics. All plots were seeded to a cereal rye/hairy vetch cover crop in Sept. 2013, and were either roller-crimped (NT and ST) or tilled-in (CT) in late spring of 2014. Each tillage treatment was split into two fertility regimes—one based entirely on preplant granular fertilizer, and the other split between the granular fertilizer and post-planting fertigation—to test the effect of fertigation on yields under the typically N-limited reduced tillage conditions. Yields of pepper were equal among the three tillage treatments, with preplant treatments averaging 19.0 Mg·ha⁻¹ and split fertility treatments averaging 14.7 Mg·ha⁻¹. Yield of broccoli was highest in CT treatments, averaging 5.4 Mg·ha⁻¹, with no difference between ST and NT treatments. Weed measurements taken three weeks after planting showed that CT treatments had significantly more weed biomass than NT and ST treatments, demonstrating that early season weed suppression by the cover crop mulch was effective. Soil growing degree days was greatest under CT management for both broccoli and pepper, and higher in ST than NT in pepper plots, but not in broccoli plots. In summary, reduced tillage systems maintained yields of peppers, but not broccoli, while providing early season weed suppression. Split application of fertilizer through use of fertigation did not increase yields.

Primary Objectives:

1. Determine effect of tillage system and fertilizer application timing on yield of broccoli and bell pepper
2. Assess impacts of fertigation on plant N status and nitrate leaching
3. Evaluate weed suppression by rolled cover crop mulch

Materials and methods

A field experiment was conducted on loam soils at the Iowa State University Horticulture Research Station in Ames, IA, in 2013-14. Each crop (broccoli and pepper) was arranged in a split-plot randomized complete block design with four replications. The entire field was planted to a mixture of cereal rye and hairy vetch, and broccoli 'Gypsy' and bell pepper 'X3R Red Knight' were each planted on half of the field. The whole-plot tillage treatments were conventional-till (CT), strip-till (ST), or no-till (NT). The subplot fertility treatments were preplant fertilizer only, split fertilizer application, or no fertilizer (control). Field operations and major data collection events are listed in Table 1.

Cover crop management

Before cover crop establishment, the soil was rototilled and compressed with a cultimulcher. The cover crop was established using a grain drill with 25-cm row spacing on 10 Sept. 2013 at 101 kg·ha⁻¹ for cereal rye and 28 kg·ha⁻¹ for hairy vetch. For ST and NT treatments, the cover crop was terminated using a roller-crimper on 3 June 2014, and was roller-crimped again on 11 June 2014 after residue began to spring back up. At the time of termination, the cereal rye was at anthesis and the hairy vetch was in full flower.

Tillage treatments.

Strips that were 37.1 cm wide were tilled in ST plots on 14 Nov. 2014 using a Hiniker 6000 strip tiller. Strips were tilled again on 11 June 2014, when fertilizer was banded. In NT plots, a band of soil was loosened, and preplant fertilizer was applied using the Hiniker strip tiller with the discs and rolling basket disengaged. In CT plots, cover crop was mowed on 7 May 2014 using a Rhino[®] flail mower and incorporated with a rotary tiller. On 11 June 2014, preplant fertilizer was surface applied by hand, and the entire plot was tilled to create a seedbed. Photos of tillage treatment plots can be found in figure 1.

Fertility treatments.

Both fertility treatments supplied 168 kg·ha⁻¹ N for broccoli and 90 kg·ha⁻¹ N for bell pepper. In the preplant fertility treatment, the entire amount of N was applied using Chick Magic[®] dehydrated poultry manure fertilizer. The poultry manure fertilizer was applied with a sidedresser mounted on the Hiniker strip tiller and delivered via a tube on the backside of the shank at a depth of 10 cm. In the split fertility treatment, two-thirds of N was applied using poultry manure fertilizer, and the remaining one-third was from Phytamin Fish Gold[®] liquid fertilizer via fertigation. Phytamin Fish Gold was selected due to its compatibility with drip irrigation systems and its high percentage of soluble N (4.1%). The split application subplots were fertigated four times, beginning 4 July 2014, and repeated at 10-14 d intervals. The final application was timed to match peak N demand by plant, around eight weeks after transplanting (Sanchez and Doerge, 1999). The liquid fertilizer was injected into the drip irrigation system using a fertilizer injector. The control treatment and guard rows were not fertilized.

Vegetable culture.

Pepper seeds were sown on 11 Apr. 2014 into an organic, compost-based growing medium in 288-cell plug trays. Pepper seedlings were potted up into 72-cell plug trays on 8 May and moved outdoors to harden off on 30 May 2014. Broccoli seeds were sown on 5 May 2014 into 128-cell plug trays and moved outdoors to harden off on 30 May 2014.

Broccoli and pepper transplants were planted in the field on 13 June 2014 with a Holland 1500[®] transplanter. Whole plots for both broccoli and pepper consisted of five 10.7-m rows spaced 76 cm apart. Broccoli transplants were spaced 30 cm apart within rows, and bell peppers were planted 46 cm apart within rows. Crops were irrigated as needed to achieve 2.5 cm of water per week. When split application subplots were fertigated, preplant only and no-fertilizer subplots were also irrigated to maintain parity of water supply among treatments. Fertigated subplots were connected to a drip header separate from preplant only and no-fertilizer subplots in order to prevent contamination of non-fertigated treatments.

Crops were scouted weekly for insect pests and disease. Major insect pests of broccoli were cabbage looper (*Trichoplusia ni* Hübner), imported cabbageworm (*Pieris rapae* L.), and large white caterpillars (*Pieris brassicae* L). *Bacillus thuringiensis* subsp. *Kurstaki* (DiPel Pro DF) was applied on 3 and 29 July 2014 as a control. The primary insect pest on pepper was green peach aphid (*Myzus persicae* Sulzer), which was controlled with an application of insecticidal soap on 18 Aug. 2014. This product was chosen because it minimized the non-target effects on beneficial insects.

Vegetable data.

Broccoli was harvested on 11 Aug. 2014, and twice weekly thereafter until 12 Sept. 2014. Green bell peppers were harvested on 21 Aug., 28 Aug., 11 Sept., and 3 Oct. 2014. Broccoli and peppers were graded according to marketability (USDA, 2005; 2006), and weight and number of fruits/heads were recorded. Average length and width of peppers were determined by measuring 10 marketable fruits per plot for each harvest. If total number of marketable fruits was less than 10, only that number were measured. Average diameter of broccoli heads was determined by measuring five heads per plot at each harvest. Dry weight was determined for each crop by harvesting two whole representative plants from each subplot and drying at 67 °C in a forced air oven until plants reached a constant weight. Broccoli plants were sampled at harvest, and the head was included for the dry-weight measurement. Pepper plants were sampled at last harvest, and any remaining fruit were removed before dry weight determination.

On 8 Aug. 2014, five plants from the middle of each subplot row were selected for measurement of leaf chlorophyll, plant height, and stem girth. Leaf chlorophyll, which is highly correlated with N content of leaves (Wood et al., 1992), was measured using a SPAD-502 Plus chlorophyll meter. For each of five plants, four readings were taken on the most recently developed, fully expanded leaf and averaged. Plant height was determined by measuring the distance from the soil at the base the plant to the tip of the highest leaf. Stem girth was measured 2 cm above soil by using digital calipers. Leaf-petiole samples for N concentration determination were taken to on 8 Aug. 2014 according to method described by Jones and Case (1990).

Cover crop and weed data.

Cover crop biomass was determined from whole plant samples harvested from two 50 × 50 cm quadrats from each whole plot on 7 May 2014 for CT and 3 June 2014 for NT and ST. Roots were washed to remove soil and plants were oven dried at 67 °C before weighing. Weeds were sampled on 2 July 2014 from two 25 × 25 cm quadrats each from the in-row and between-row regions of each whole plot. Weeds were counted, identified as either grasses or broadleaf plants, and dried at 67 °C before weighing.

Nitrate leaching data

Lysimeters were installed to 24-inch depth and sealed using silica flour and bentonite pellets to prevent surface water from running down the side surface of the lysimeter. In absence of recent rain, drip irrigation was run 24 hours prior to pulling vacuum on lysimeters. After 24 hours of vacuum, leachate was pumped out of lysimeters and transferred into sample bottles for nitrate analysis. Samples were collected every 7-10 days from weeks 2-8 after planting, and biweekly after that.

Economic analysis

An analysis of profitability was conducted using actual per-acre marketable crop yields and accounting for fixed and variable costs of production. Hand weeding and harvest labor were recorded, while other costs were determined using standard cost estimates developed by Iowa State University. Separate analyses were conducted using organic as well as conventional prices, reflecting the reality that crops managed organically, but grown in non-organic soil, usually must accept non-organic prices.

Data analysis.

Analysis of variance (ANOVA) was conducted using the GLIMMIX procedure in SAS to determine the effect of tillage and fertility treatments on yield, fruit size, head diameter, leaf N, leaf chlorophyll, plant height, stem girth, cover crop and vegetable plant dry weight, soil growing degree days, weed density and biomass, and nitrate concentration of leachate. Block was treated as a random factor in all analyses. Data were log-transformed as necessary to satisfy the homogeneity of variance and normality assumptions of ANOVA. Means were separated using Fisher's least significant difference ($P \leq 0.05$).

Results

Growing degree days and rainfall.

Accumulation of growing degree days (GDD, base 10 °C, max 30 °C) in 2014 followed a trend similar to the 30-yr average, although cool July temperatures reduced season-end GDD by 110 units compared to the average (Fig. 2). Monthly rainfall was 5.8 and 4.2 cm below average in May and July, but 18.7 and 5.3 cm above average in June and August, respectively. The June rains were concentrated in the second half of the month, causing a three-week period of consistently saturated soil conditions starting soon after transplanting.

Cover crop

As expected, cover crop biomass in NT and ST plots was greater than in CT plots due to their delayed termination date. Table 2 shows that cover crop biomass in NT and ST plots had an average of 6.6, 2.3, and 8.8 Mg·ha⁻¹ more shoot, root, and total dry weight, respectively, compared with CT. There was no difference between NT and ST. Nitrogen (N) concentration in cover crop residue was lowest for NT and ST treatments, with carbon-to-nitrogen (C:N) ratios of 21:1, 38:1, and 41:1 for CT, ST, and NT, respectively.

Pepper yield

There was no difference in marketable yield among tillage treatments (Table 3, Fig. 3). Averaged across tillage treatments, preplant fertility plots yielded 28% higher than split fertility plots. Yields of plants in the unfertilized control were 53% and 39% lower than in preplant and

split fertility treatments, respectively. Treatment effects on marketable number of fruits followed the same trend as weight, with no differences among tillage treatments. Nonmarketable yield and number were similar among tillage treatments, but higher in preplant and split than in no-fertilizer treatments. Average pepper length and width were both unaffected by tillage treatment, although peppers from unfertilized plots had lower average width than peppers from both preplant and split fertility treatments.

Broccoli yield

Both weight and number of marketable broccoli heads were higher in CT than NT or ST. Averaged across fertility treatments, yields in CT were 40% and 69% greater than in ST and NT treatments, respectively (Table 3, Fig. 3). However, means of the nonsignificant tillage \times fertility interaction show that yield of NT treatments using preplant fertility was numerically equal to both fertilized CT treatments, suggesting that the main effect means may not accurately reflect potential broccoli yields under reduced tillage. Fertilizer had a strong effect on yield, with unfertilized treatments producing an average of 84% less than the two fertilized treatments. This reduction in yield was a result of heads maturing at an unmarketable size, with many plants failing to produce a head. There was no difference in nonmarketable weight or number among any of the treatments. Head diameter of marketable broccoli was the same among tillage treatments, but was reduced in unfertilized plots, as compared with fertilized plots.

Leaf nitrogen and SPAD

Leaf nitrogen (N) status was determined eight weeks after transplanting by analysis of dried and ground leaf-petiole samples and through estimation of leaf chlorophyll by using a SPAD meter. For pepper, N was higher in CT than NT or ST treatments, averaging 0.54% greater leaf N content (Table 4). The preplant fertility treatment increased N compared with no-fertilizer, but was not different from split application. For broccoli, there was no difference in N among tillage or fertility treatments. There was a strong correlation (Pearson's $r=0.978$, $p < 0.0001$) between treatment means of N and SPAD number.

Plant height

There was no difference among tillage treatments in height of pepper plants (Table 4). Plant height in preplant plots was greater than in split fertility plots, and plants in both preplant and split fertility plots were taller than the no-fertilizer plots. Averaged across fertility treatments, plant height of CT broccoli was 6.9 and 11 cm greater than that of ST and NT, respectively. Plant heights in preplant and split fertility plots were the same, but an average of 14.7 cm greater than in no-fertilizer plots. A tillage \times fertility interaction ($P \leq 0.001$) occurred for plant height in broccoli, where there was no difference between CT and NT when using preplant fertilization.

Stem diameter

There was no effect of tillage treatment on pepper stem diameter, but broccoli stem diameter in CT was 2.65 mm greater than in NT treatments (Table 4). There was no difference in stem diameter between CT and ST for broccoli. For both crops, there was no difference in stem diameter between preplant and split fertility treatments, but they averaged 5.3 and 2.8 mm greater than no-fertilizer for broccoli and pepper, respectively.

Plant dry weight

There was no effect of tillage on dry weight in either broccoli or pepper, but fertilization had a strong effect in both crops (Table 4). For each crop, all three means were different, with plants from preplant fertilizer treatments weighing 22% and 42% more in broccoli, and 15% and 75% more in pepper, than split fertility and no fertilizer treatments, respectively.

Soil growing degree days

The greatest number of soil growing degree days (SGDD) during early, mid, and late seasons for both broccoli and pepper occurred in CT plots (Table 5). In broccoli, there was no difference between ST and NT in any season. However, for pepper, which had a longer growing season than broccoli, ST had more SGDD than NT in all three time periods.

Weed suppression

The primary weed species present were common purslane (*Portulaca oleracea* L.), redroot pigweed (*Amaranthus retroflexus* L.), and yellow foxtail (*Setaria pumila* Poir.). Dry weight and density of weeds in both in-row and between-row regions of CT were the highest, though not significantly different from in-row regions of ST or NT (Fig. 4). Between-row regions of NT and ST, however, had fewer weeds than all other treatments, with dry weights and counts of essentially zero. The absence of weeds in these treatments is explained by the effective weed suppression provided by the rolled cover crop mulch.

Nitrate leaching

Conventional-till using split fertilizer application resulted in more nitrate leaching than all other treatments when averaged across all sampling dates (Fig. 5). Differences between treatments were most stark during June and July, decreasing later in the season. Preplant fertilizer tended to increase leaching of nitrate in no-till and strip-till treatments, but decrease leaching of nitrate in the conventional-till treatment.

Economics

Profit per acre was generally highest using the CT production system, though it was similar among tillage treatments for pepper (Fig. 6). Profit followed the same trends as yield, given that there were only small differences in the costs of production for different tillage systems. The lower prices for non-organic produce reduced profit for most NT and ST broccoli treatments to nearly zero.

Summary and conclusions

Use of cover crops is already standard practice on most organic vegetable farms, but few organic growers in the Upper Midwest have experimented with reduced tillage. Our results suggest that NT or ST might be a viable option for production of certain vegetable crops, such as bell pepper. Tillage treatment also affected measures of plant N status, but these differences did not always correspond with yield. Other factors, such as fertilizer and weed management, may also affect crop productivity in reduced tillage systems. Our data show that use of fertilizers that are low in inorganic N, such as dehydrated poultry manure, may be most effective if applied at the full rate before planting, and also that nearly total control of annual weeds can be achieved with heavy cover crop residue. However, weed growth within the crop row may be substantial and difficult to control in a rolled cover crop system. The reduction in nitrate leaching in NT and

ST plots suggests that use of cover crops and reduced tillage practices may be valuable in reducing the overall nitrate load leaching out of Midwestern crop fields.

Outreach

- Completed events and presentations
 - Strip Tillage Field Day – June 2014
 - Gave tour of field plot and showed attendees the roller-crimper and strip tiller.
 - PFI Cover Crop Boot Camp – July 2014
 - Gave a talk on managing rye and vetch in an organic no-till system to a group of farmers being trained as “ambassadors” of cover crops.
 - YouTube video – July 2014
 - Made a 7-minute, professionally edited video describing the project, providing practical information about cover crop-based reduced tillage systems, and showing what each tillage treatment plot looks like. Available on the NCR-SARE YouTube channel.
 - Fruit and Vegetable Field Day – Aug. 2014
 - Gave attendees a tour of the field plot.
 - Field Day for ISU Extension – Aug. 2014
 - Gave a short demonstration of the roller-crimper and strip tiller to a group of ISU extension educators.
 - Great Plains Growers’ Conference – St. Joseph, MO – Jan. 2015
 - Gave a 30-minute presentation on organic no-till and strip-till systems.
 - Poster at PFI Annual Conference – Jan. 2015
 - Poster at MOSES Organic Farming Conference – La Crosse, WI -- Feb. 2015
 - No-till broccoli field day at Grinnell Heritage Farm (grower collaborator) – July 2015
 - Provided an overview of the organic no-till system and showed attendees the no-till broccoli plot we established at Grinnell Heritage Farm.
 -
- Upcoming events and presentations
 - Fruit and Vegetable Field Day – Aug. 2015
 - Poster at ASHS Annual Conference – Aug. 2015

Tables and figures



Fig.1 Pepper plants in no-till (left), strip-till (center), and conventional tillage (right) plots.

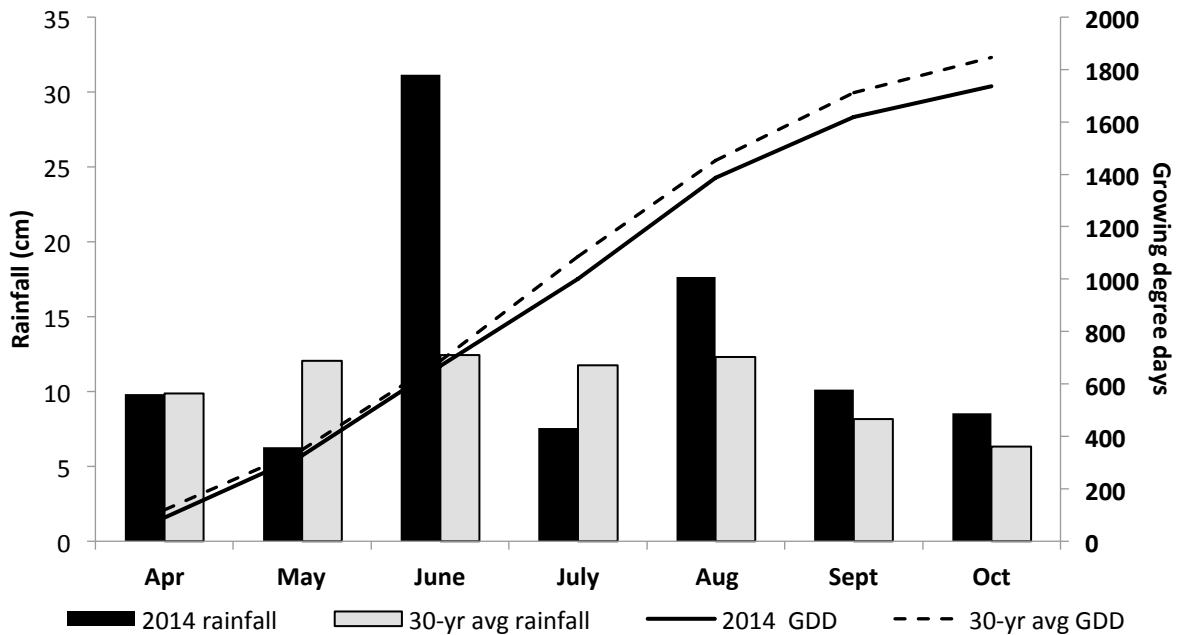


Fig. 2. Total monthly rainfall and accumulated growing degree days (GDD) during the 2014 growing season compared with the 30-year averages (1985-2014) in Ames, IA. A base temperature of 10°C was used in calculation of GDD. Long-term weather data were obtained from the Iowa Environmental Mesonet.

Table 1. Schedule of major field operations and data collection events in 2014.

Event	Date	Treatment ^z	
		Tillage	Fertility
Seeded cover crop	10 Sept.	All	All
Tilled strips	14 Nov.	ST	All
Cover crop biomass samples taken	7 May	CT	All
Cover crop biomass samples taken	3 June	ST, NT	All
Cover crop flail mowed and tilled in	7 May	CT	All
Cover crop roller-crimped	3 June	ST, NT	All
Fertilizer surface applied in row	11 June	CT	Preplant, Split
Seedbed made using rotary tiller	11 June	CT	All
Strips re-tilled	11 June	ST	All
Fertilizer banded	11 June	ST, NT	Preplant, Split
Broccoli and pepper transplanted	13 June	All	All
Weed biomass samples taken	2 July	All	All
Fertigation [1]	4 July	All	Split
Crop rows hand weeded	16 July	All	All
Fertigation [2]	17 July	All	Split
Fertigation [3]	26 July	All	Split
Fertigation [4]	4 Aug.	All	Split
Plant height, stem girth, SPAD measurements taken; leaf-petiole samples collected	8 Aug.	All	All
First broccoli harvest	11 Aug.	All	All
First pepper harvest	29 Aug.	All	All
Final broccoli harvest	12 Sept.	All	All
Final pepper harvest	3 Oct.	All	All

^zColumns indicate to which tillage and fertility treatment the event applies.

Table 2. Shoot, root, and total dry weight (lbs/A) and carbon-to-nitrogen (C:N) ratio of cereal rye-hairy vetch cover crop at termination

Treatment	Shoot	Root	Total	C:N ratio
	(Mg·ha ¹)			
Conventional-till	6.4 b ^z	0.7 b	7.1 b	21:1 c
Strip-till	12.7 a	2.9 a	15.6 a	39:1 b
No-till	13.3 a	3.0 a	16.2 a	41:1 a
	***	***	***	***

^zMeans within the same column followed by the same letter are not significantly different according to Fisher's protected least significant difference test (LSD) ($P \leq 0.05$).

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; NS nonsignificant.

Table 3. Cumulative weight ($\text{Mg}\cdot\text{ha}^{-1}$) and number (1000s/ha) of marketable and nonmarketable peppers and broccoli, average pepper length and width, and average broccoli head diameter (cm) as affected by tillage and fertility treatments.

Treatment ^z	Marketable		Nonmarketable		Fruit length	Fruit width	Head diameter
	Weight	Number	Weight	Number			
Pepper							
Tillage (T)							
CT	15.15 ^y	91	3.68	41	8.91	7.93	----
ST	14.03	88	3.18	32	8.83	7.93	----
NT	13.44	83	2.72	27	8.51	7.50	----
<i>Significance</i>	NS	NS	NS	NS	NS	NS	----
Fertility (F)							
Preplant	18.93 a	114 a	4.18 a	42 a	8.93	8.01 a	----
Split	14.74 b	90 b	3.63 a	38 a	8.74	7.98 a	----
No fert	8.94 c	58 c	1.77 b	21 b	8.58	7.37 b	----
<i>Significance</i>	***	***	***	***	NS	**	----
Broccoli							
Tillage							
CT	5.37 a	25 a	1.23	8	----	----	8.75
ST	3.83 b	17 b	1.02	7	----	----	8.60
NT	3.18 b	17 b	0.81	5	----	----	7.87
<i>Significance</i>	***	**	NS	NS	----	----	NS
Fertility							
Preplant	5.98 a	28 a	1.40	9	----	----	9.29 a
Split	5.51 a	26 a	0.88	6	----	----	8.75 a
No fert	0.90 b	5 b	0.78	5	----	----	7.19 b
<i>Significance</i>	***	***	NS	NS	----	----	*

^zCT= Conventional tillage; ST=strip tillage; NT=no tillage; Preplant = only preplant fertilizer; Split = 2/3 of N from preplant fertilizer and 1/3 from post-planting fertigation; No fert = unfertilized control.

^yMeans in a column within the same crop and treatment followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$). The tillage \times fertility interaction was nonsignificant.

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; NS nonsignificant.

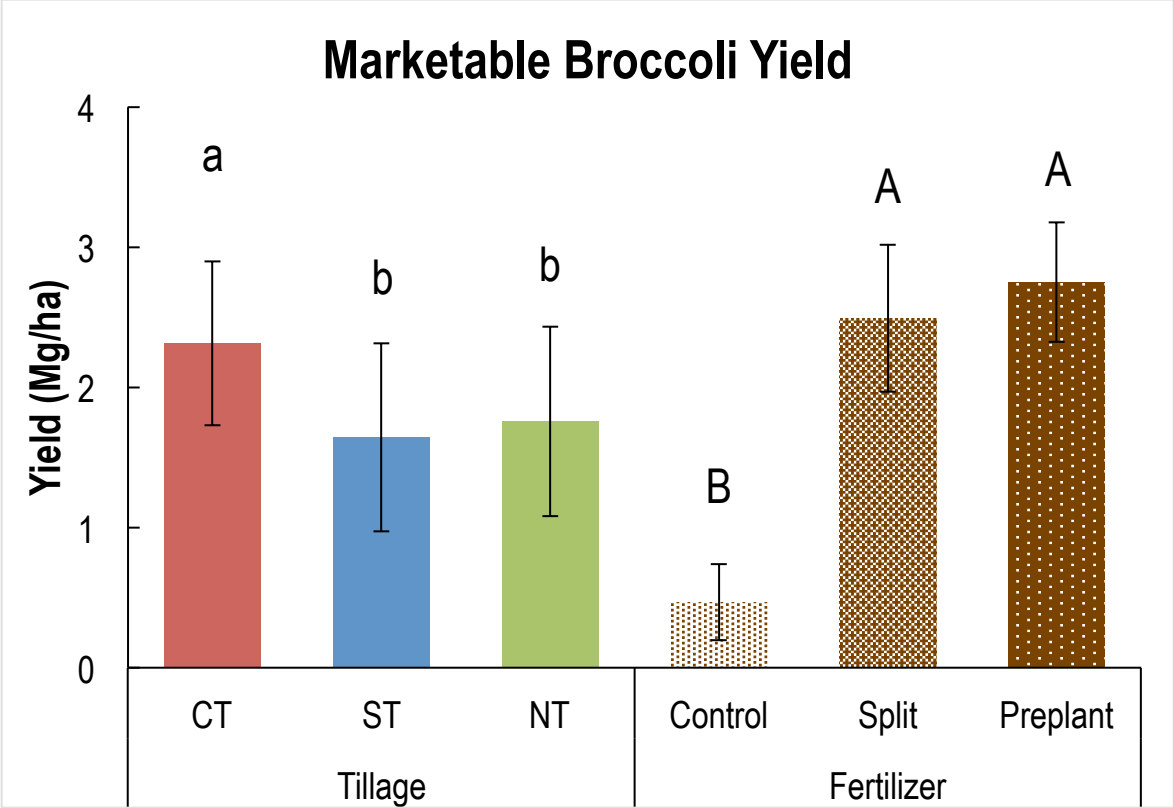
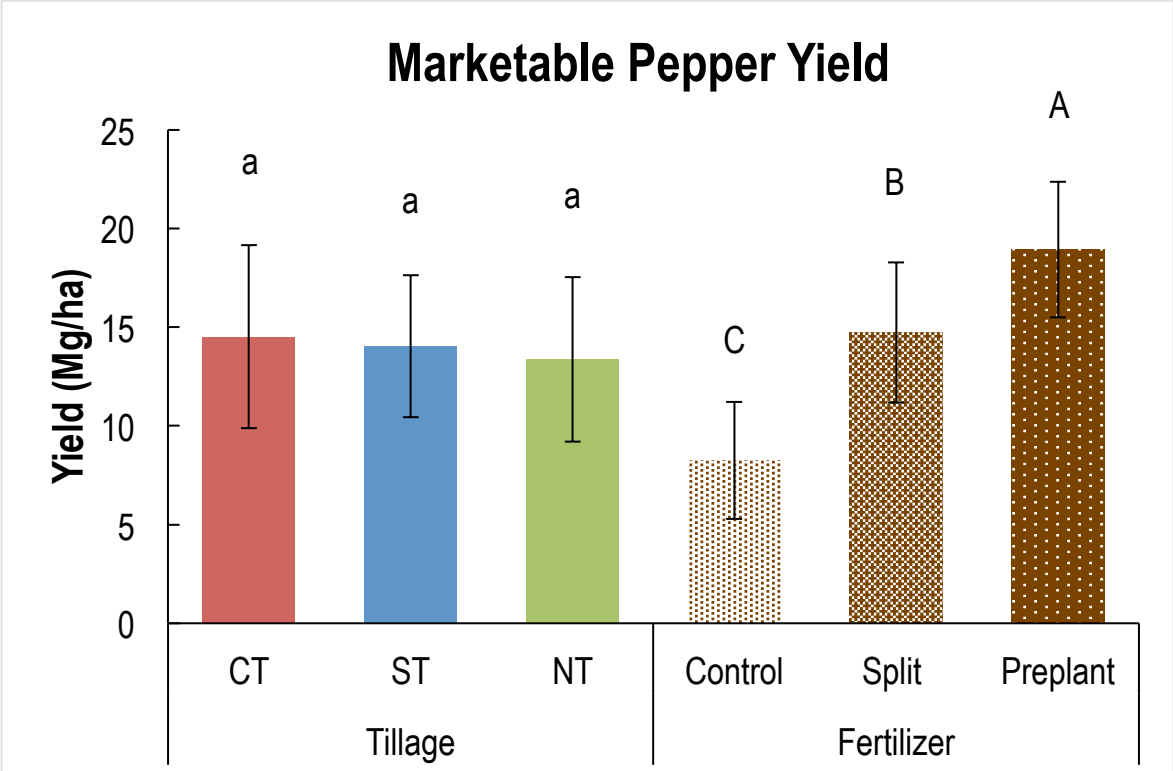


Figure 3. Yield of peppers (top) and broccoli (bottom) under no-till, strip-till, and conventional-till management, and fertilized using only preplant granular fertilizer, a combination of preplant granular and post-plant fertigation, or no fertilizer. Mean separation by least significant difference ($P \leq 0.05$). Error bars refer to standard errors of the mean.

Table 5. Effects of no tillage, strip tillage, and conventional tillage on accumulated soil growing degree days during early^z, mid^y, and late^x seasons of broccoli and pepper.

Treatment ^w	Early	Mid	Late
	(SGDD ^y)		
Broccoli			
CT	388 a ^u	767 a	1160 a
ST	343 b	681 b	1044 b
NT	335 b	662 b	1017 b
<i>Significance</i>	***	***	***
Pepper			
CT	485 a	1036 a	1347 a
ST	439 b	937 b	1247 b
NT	409 c	868 c	1156 c
<i>Significance</i>	***	***	***

^zEarly season: date of planting until 14 July for broccoli and 21 July for pepper. Date of planting was 14 June for both broccoli and pepper.

^yMidseason: date of planting until 13 Aug. for broccoli 28 Aug. for pepper.

^xLate season: as date of planting until 15 Sept. for broccoli and 2 Oct. for pepper.

^wCT= conventional tillage; ST=strip tillage; NT=no tillage.

^ySGDD = soil growing degree days (base 10 °C, max 30°C).

^uMeans within the same column and crop followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; NS nonsignificant.

Table 4. Leaf nitrogen, SPAD readings, plant height, stem girth, and dry weight of broccoli and pepper plants as affected by tillage and fertility treatments.

Measurements were taken on 8 Aug. 2014.

Treatment ^z	Leaf N ^y (%)	SPAD	Plant height (cm)	Stem girth ^x (mm)	Dry weight ^w (g)
Pepper					
Tillage (T)					
CT	4.97 a ^y	59.89 a	37.30	10.33	93.48
ST	4.44 b	56.96 b	35.02	8.54	90.93
NT	4.42 b	56.74 b	32.74	8.26	77.98
<i>Significance</i>	*	*	NS	NS	NS
Fertility (F)					
Preplant	4.82 a	59.94 a	39.25 a	10.53 a	109.58 a
Split	4.57 ab	57.06 b	36.37 b	9.41 a	94.62 b
No fert	4.43 b	56.60 b	29.44 c	7.19 b	58.20 c
<i>Significance</i>	*	**	***	**	***
T × F	NS	NS	NS	NS	NS
Broccoli					
Tillage					
CT	4.33	70.90	48.08 a	16.85 a	195.28
ST	4.15	70.75	41.16 b	15.22 ab	175.08
NT	4.14	67.48	37.08 b	14.20 b	156.16
<i>Significance</i>	NS	NS	*	*	NS
Fertility					
Preplant	4.41	73.37 a	47.22 a	17.57 a	219.26 a
Split	4.21	70.82 a	46.77 a	16.82 a	180.35 b
No fert	3.99	64.93 b	32.34 b	11.88 b	126.92 c
<i>Significance</i>	NS	***	***	***	***
T × F	NS	NS	***	NS	*

^zCT= Conventional tillage; ST=strip tillage; no tillage (NT). Preplant = only preplant fertilizer; Split = 2/3 of N from preplant fertilizer and 1/3 from post-planting fertigation; No fert = unfertilized control.

^yPercent nitrogen of dried and ground leaf-petioles. Samples were comprised of 20 broccoli leaves or 40 pepper leaves.

^xDiameter of stem measured 2 cm above soil level.

^wDry weight of two whole plants. Pepper fruits were removed; broccoli heads were included.

^vMeans in a column within the same crop and treatment followed by the same letter are not statistically different according to Fisher's protected LSD ($P \leq 0.05$).

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; NS nonsignificant.

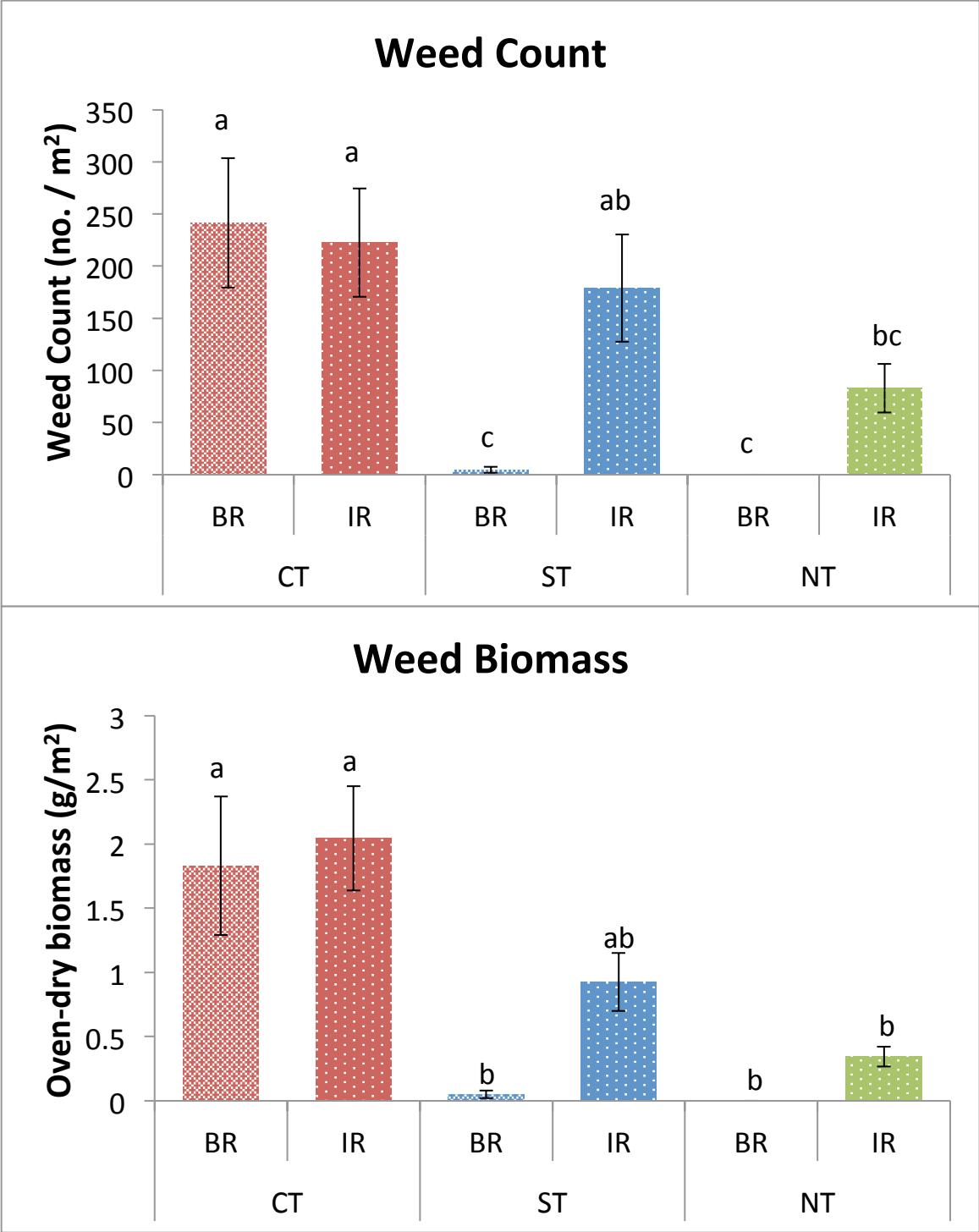


Figure 4. Weed biomass (left) and count (right) per m² from samples taken on 7/2/14, three weeks after transplanting. In-row (IR) refers to the 12 inch-wide region centered on the crop row and between-row (BR) refers to the space between adjacent in-row regions. Mean separation by least significant difference ($P \leq 0.05$). Error bars refer to standard errors of the mean.

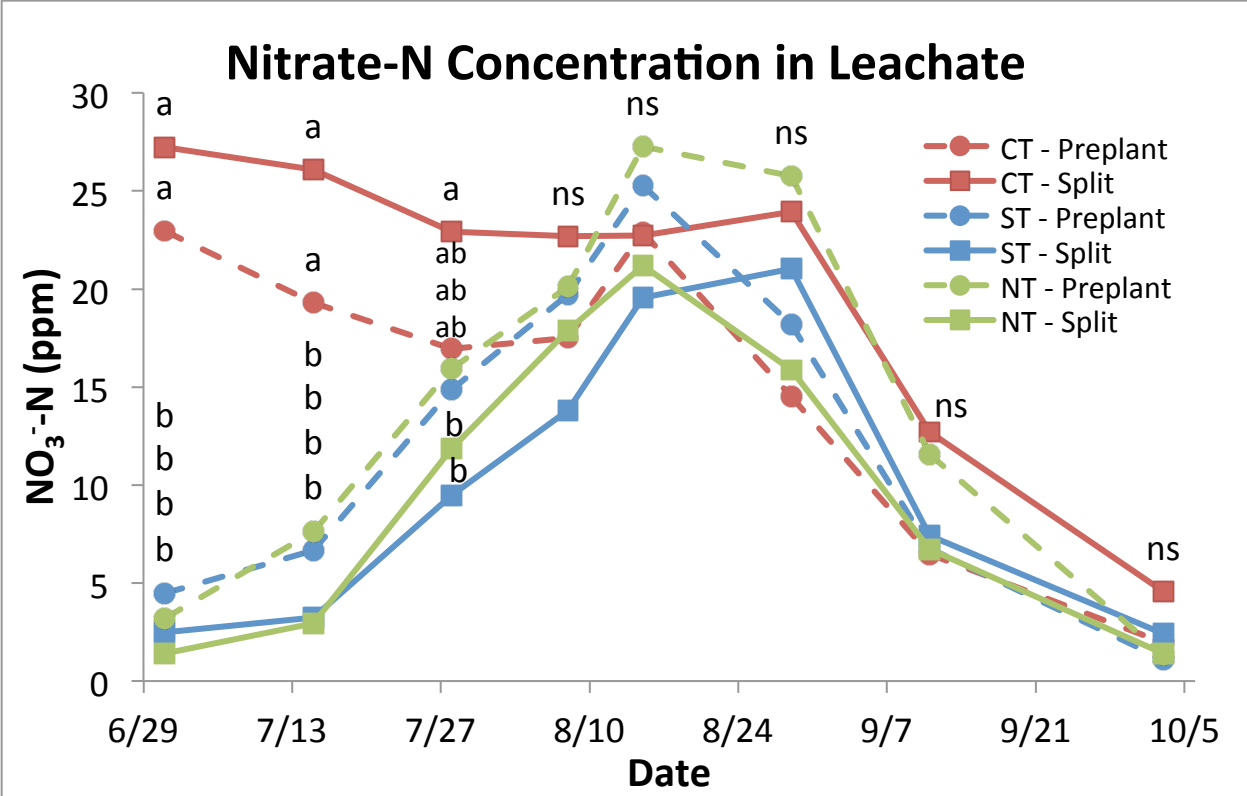
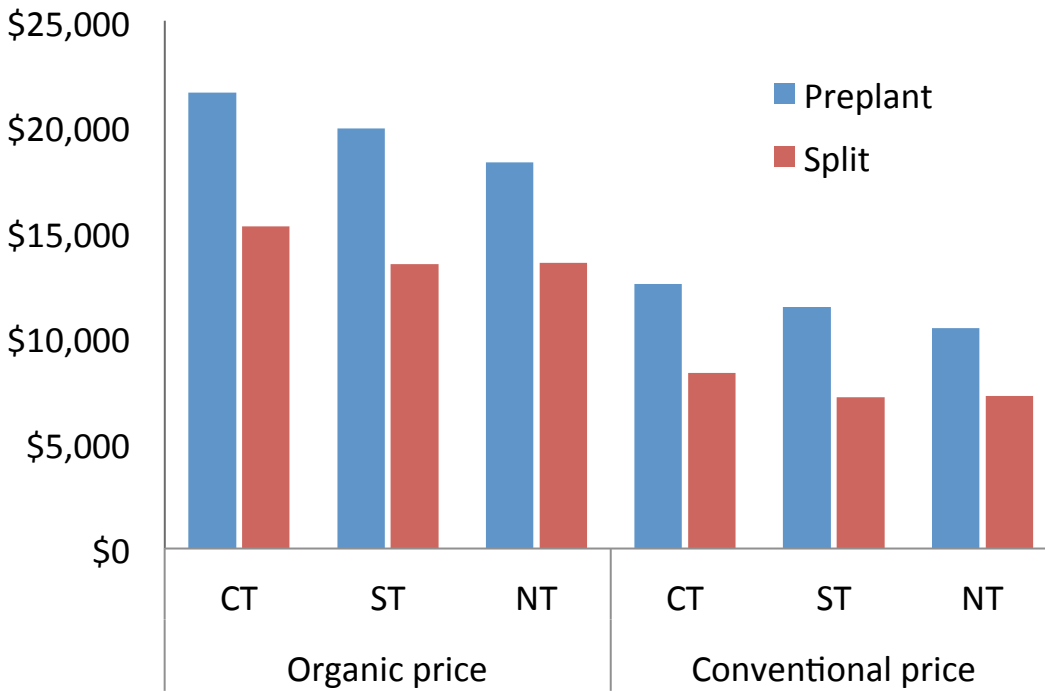


Figure 5. Parts-per-million of nitrate-N measured in leachate samples in 2014 from lysimeters installed to 24" depth. Mean separation on each date by least significant difference ($P \leq 0.05$).

Profit per Acre (Pepper)



Profit per Acre (Broccoli)

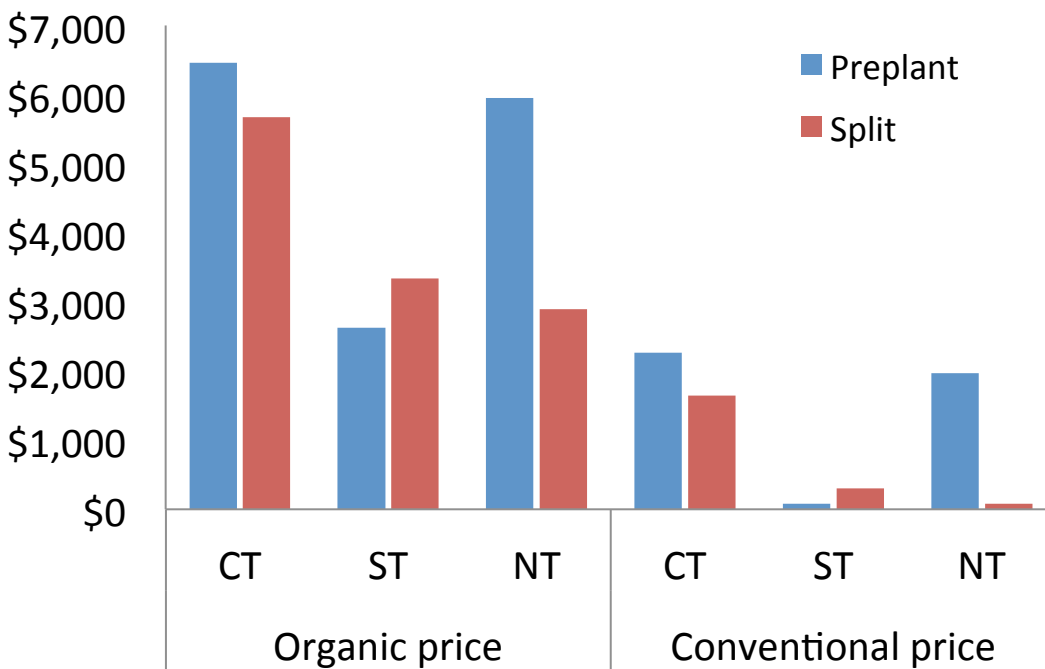


Figure 6. Profit per acre of broccoli and pepper under no-till (NT), strip-till (ST), and conventional-till (CT) management.