Research report submitted to:

Organic Farming Research Foundation
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Santa Cruz, CA 95061
831-426-6606
www.ofrf.org

Date: **December 11, 2000**

Title: **Development and Evaluation of Biologically-Integrated Conservation Tillage Systems for Organic Vegetable Production**

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Locations: Oregon State University Research Farm, Corvallis, OR

Project period: 1999-2000

Project budget: $11,900

Funding provided by OFRF: $4,825.00

OFRF project number: 99-21, awarded Fall 1999

Introduction

A primary goal in developing environmentally sound and profitable farming systems has been to prevent soil degradation and erosion loss, and wherever possible, enhance soil quality through organic matter management. Conventional tillage practices currently used for vegetable production in the Willamette Valley involve from 5-8 passes over the field. For the past four years we have been working with vegetable growers in the Willamette Valley to develop an integrated system of vegetable production using winter annual cover crops and rotary strip- tillage. The strip-till system uses a single pass of a strip-rototiller and tills approximately 30% of the soil surface. In nine on-farm trials in 1997 and 1998, this strip-till system produced a net average increase in profit to the participating sweet corn growers of approximately $50 per acre compared to standard tillage practices. These trials have been conducted on "conventional" farms, however, and herbicides have been used to suppress cover crops and control weeds. In the experiment described here, we wanted to evaluate the feasibility of strip-till vegetable production in an organic system using no herbicides.

Procedures

An experiment was established at the OSU Vegetable Research Farm near Corvallis, OR in a block that has been farmed using organic production practices since 1995. Sweet corn was grown during the summer of 1997 and the plot was fallowed during the summer of 1998. In the fall of 1998, a randomized block split-plot design experiment was initiated with 2 cover crops and 3 tillage treatments (described below). The two cover crop treatments included (1) a mixture of 'Steptoe' barley, (60 lbs/acre), common vetch (50 lbs/acre) and phacelia (10 lbs/acre) and (2) a mixture of 'Celia' triticale (60 lbs/acre), common vetch (50 lbs/acre) and phacelia (10 lbs/acre), Tillage strips (25 x 120 ft) were randomized within each of four replicated blocks.

Prior to cover crop planting in the fall, a pelletized fish fertilizer (Oregon BioGrow® 9-3-5) was applied at 200 lbs/acre to provide a small amount of N to assist establishment of the cover crops. A Lely roterra@ was used to incorporate the fertilizer and prepare a seedbed. Cover crop treatments were randomized within future tillage treatments. Cover crop species were mixed and hand seeded on Oct. 23, 1999, in plots 25 x 60 ft. A spike-toothed harrow was used to incorporate the cover crop seed. Cover crops in all treatment plots were shredded on May 14 using a Buffalo® stalk chopper with rolling blades. This method did not adequately suppress the cover crop growth and a flail mower was used on all plots on May 21 immediately prior to tillage. Tillage treatments included (1) conventional tillage (CT) using a power spader, followed by 2 passes with a Lely roterra®, (2) strip-tillage/mow (ST-M) using a single pass of a Northwest Farm Tillers 12' rototiller modified to till four 6 inch-wide strips approx. 6 inches deep (with between row cover crops and weeds suppressed with successive mowing), and (3) strip-tillage/cultivate (ST -C), with strip tillage as in Treatment 2, but with between row vegetation suppressed by mowing and a single cultivation with a Buffalo high residue cultivator. Although we use the term "conventional" to describe the soil preparation treatment here, the spader and roterra tillage doesn't fully invert the soil that typifies conventional moldboard plow tillage systems.

In the strip-till plots, BioGrow fish fertilizer was applied by hand in a 6-inch wide band over the tilled strip at a rate of 980 lbs/acre (88 lbs/N/acre). In the CT plots, strings were stretched over the rows to be planted and fish fertilizer applied similarly to the ST plots. The strip tiller was then used to incorporate the fish fertilizer in ST and CT plots.

Broccoli (Var. = 'Arcadia') was transplanted on May 28 using a mechanical transplanter and skips were filled by hand to assure a uniform stand. Irrigation was applied immediately after transplanting and periodically during the growing season on an as-needed basis.

A DR® weed trimmer equipped with a shield was used to mow between the broccoli rows in the ST-M and ST-C plots, with mowing conducted on June 14 and June 27. The CT and the ST- C plots were cultivated with the Buffalo cultivator on June 27. Weeds within the rows were controlled by hand hoeing on July 1 and July 7. No insecticides were applied during this experiment.

Data Collection

Cover crop above-ground biomass. Two 0.25 m^2 quadrats were randomly selected within each cover crop treatment and cover crops clipped at the soil surface on May 13, 1999. Cereals, vetch, and phacelia were separated into their respective species and placed in paper bags. Very few weeds were present in the samples and were not included. Samples were taken to the laboratory and oven-dried at 60°C for 60 hours and weighed. Cover crop tissue sub-samples were ground and analyzed for total N and C by the OSU Central Analytical Laboratory (CAL).

Soil nitrate and leaf nitrogen. Soil nitrate levels were estimated by taking two soil cores 15 cm deep within the broccoli row and two cores between the broccoli rows for each plot on July 14. Soil nitrate levels were determined by Agri-Check Laboratories, Umatilla, OR. Ten intermediate age broccoli leaves were randomly selected within each plot on July 13 and on July 28 and analyzed for total N by the OSU-CAL. Broccoli yield. Within each treatment block, a 4 row by 50 ft was marked off and broccoli heads cut, counted, graded and weighed on Aug. 10 and Aug. 16. Grading standards were based on those used by a large frozen broccoli packer in the Willamette Valley (Norpac, Inc., Stayton, OR) and included Number 1, Number 2, and culls.

Weed abundance. A 0.25 m^2 rectangular quadrat was used to estimate weed density on one sampling date, June 23, or 25 days after transplanting broccoli and before the between-row cultivation in the ST -C plots. Four samples were taken within each plot and all samples were located between the crop rows. All broadleaf species were identified and counted.

Insect pest and natural enemy abundance. Ten broccoli plants were randomly selected within each plot and visually examined for presence and abundance of insect pests (aphids and caterpillars) and natural enemies. Only the central four leaves of each plant were examined. Sampling was conducted on seven dates between June 28 to August 11. For flea beetles, sampling was conducted only during the two-week period in late June when the beetles were present in the field. Broccoli plants were sampled for insect abundance on a weekly basis during the growing season by visually examining the 4 central leaves on 10 plants per plot. On Aug. 11, just prior to broccoli harvest, 10 broccoli heads within each plot were cut and dissected to determine the abundance of insects within the heads.

Results

Cover crop above-ground biomass. There was more than twice the biomass of barley than triticale in the plots, however biomass of vetch and phacelia was quite similar between the cover crop treatments (Table 1). Vetch clearly contributed the greatest biomass and nitrogen of the cover crop components, with slightly more than 70 kg N/ha.

Soil nitrate and leaf nitrogen. Soil nitrate levels ranged from 6.7 to 9.5 ppm among the cover crop/tillage treatments (Table 2). These levels are within the range of values found in our previous work involving conventional production of broccoli. Pooled across cover crops, CT had higher soil nitrate levels in the broccoli row than the ST treatments. Soil nitrate levels were higher between the rows in the CT than the ST -M, but the ST -C contained the highest level. Soil nitrate was slightly higher in the barley treatments than in the triticale.

Percent total nitrogen in the broccoli leaves ranged from 3.6 to 5.2 among the treatments on July 13 (Table 3). CT had higher N than either of the ST treatments and the barley cover crop mixture had slightly higher levels than triticale.

Broccoli Yield. There was very similar total number of usable broccoli heads among the treatments, with a trend toward more No.1 heads in the CT than in the ST treatments (Table 4). Broccoli yield, however, was significantly greater for CT than the ST treatments, with CT producing nearly one ton/ha more yield (Table 5). Most of this yield increase was in No.1 grade heads, which were larger than No.1 heads in the ST plots. There was no cover crop effect on yield.

Weed Abundance. Density of purslane *(Portulaca oleracea* L), hairy nightshade *(Solanum sarrachoides* Sendtner), and Persian speedwell *(Veronica persica* Poir) were all greater in the CT plots than in the ST plots ($p<0.001$) (Fig. 1). Purslane continued to emerge in the CT plots in spite of repeated cultivations. Although abundance of chickweed was low compared to other weeds, ST plots had more chickweed than CT ($p <0.001$) (Fig. 1). The stimulatory effect of tillage on weed germination is well known and the lack of tillage in the ST plots apparently reduced weed germination in this trial. However annual blue grass *(Poa annua)* was present throughout the ST plots, since the mowing had little effect on the low-growing grass.
Insect Abundance. Dramatic differences in abundance of flea beetles *(Phyllotreta brassicae)* were observed among the tillage treatments, with significantly ($p<0.001$) more beetles found on the CT plots than in the ST plots on all four sampling dates (Fig. 2). Flea beetles in the CT plots caused a considerable ragging of the broccoli leaf edges. Flea beetles disappeared from the broccoli soon after the June 29 sampling date and the broccoli rapidly grew out of the damage.

There were no significant treatment effects of tillage or cover crops on pest or natural enemy abundance sampled on the broccoli leaves during the growing season (data not shown). Nor were there any significant effects of treatments on insect contamination of broccoli heads (Table 6).

Discussion

Nitrogen availability to the broccoli crop may be a key factor in the yield reduction shown in the ST treatments. The CT treatment apparently mineralized more N, as indicated by the soil nitrate tests. The competition of the between-row vegetation for nutrients and water is also a factor. Although the mowing suppressed the regrowth of the barley fairly well, there was some regrowth of the triticale. In the ST plots, annual blue grass *(Poa annua)* combined with other summer annual weeds to form a living vegetative cover between the rows. Excellent weed control within the broccoli rows was maintained using hand hoeing, however the clean-cultivated strips were rather narrow (about 6") and competition from between-row vegetation was likely.

The dramatic reduction of flea beetle infestations in the strip-till plots has implications for future control strategies for organic growers. However the mechanism that is causing the differences in insect abundance among the tillage treatments is not understood.

The relatively high level of imported cabbage worm *(Pieris rapae)* larvae found in the heads is interesting. Although organic growers might use *Bacillis thuringiensis* (Bt) to control worms in broccoli, we did not have adequate spray equipment to apply insecticides. Also, we had planted 2 x 35 m strips of buckwheat *(Fagopyron esculentum)* along the outside edges of the experimental block as insectary plants to provide nectar and pollen for beneficial insects. Unfortunately, many insectary plants also provide resources for pest species, and in this experiment we observed literally hundreds of the white *P. rapae* moths feeding on the buckwheat and moving directly into the broccoli to lay eggs. In other OFRF-supported work, we have also shown that buckwheat is attractive to *P. rapae.* Therefore we believe that buckwheat should not be planted near plantings of cruciferous crops.

The rotary strip tiller used in this trial does not prepare a very wide or deep tilled strip (approx. 6" wide x 6" deep) compared to the newer transtiller which tills about 12" wide and 14" deep. In future work with strip-tillage in organic systems, we will use the transtiller. Additional suppression of the cover crop and weeds growing between the rows is also necessary, and future research will focus on thermal vegetation control devices. Thermal weed control involves the injection of superheated gas into a semi-enclosed containment vessel moving over the soil surface and has been shown to be more effective with larger vegetation that traditional propane flaming (J. Luna, unpublished data). Higher rates of fertilizer application would also help assure availability of N to the crop. One of the major constraints in this project was in-row weed control, since the row was too narrow to use cultivation equipment. Hand hoeing was also difficult in the narrow strips because of the compacted, untilled areas between the rows constricted the action of the hoes.

Fig. 1. Effects on tillage systems on weed abundance sampled between broccoli rows, 25 days after transplanting broccoli. Values are mean number of weed species per 0.25 m^2, pooled across cover crop treatments (N = 8). Treatment codes are: CT = conventional tillage, ST -C = strip-till with cultivating vegetation between-rows, and ST -M = strip-till with mowing vegetation between rows.

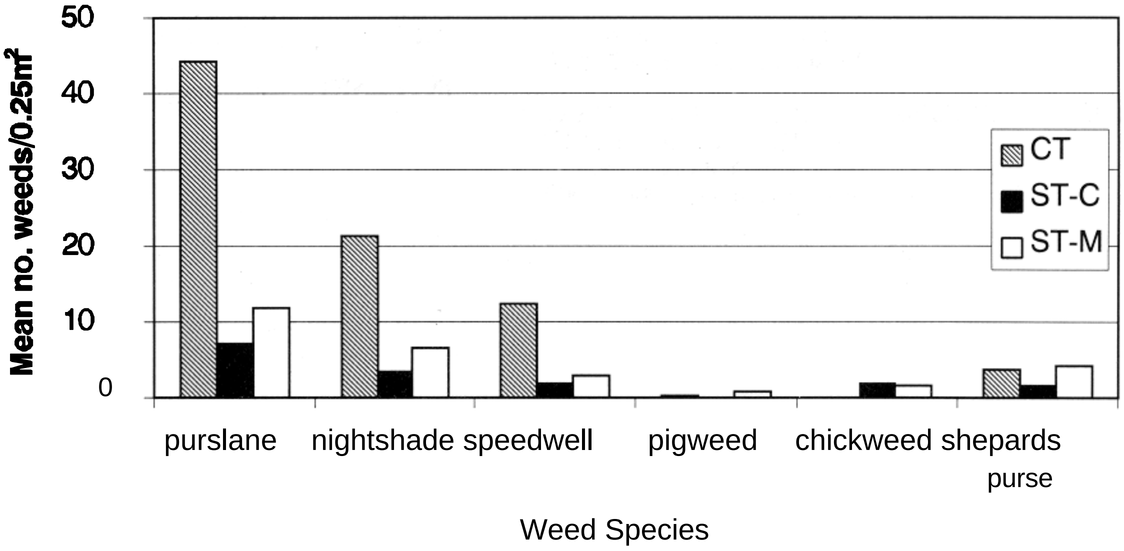

Fig. 2. Effects of tillage systems on abundance of cabbage flea beetles on broccoli seedlings. Values are mean number of flea beetles per plant, based on sampling 12 plants per replicate, 4 replicates, and pooled across both cover crop treatments (N = 96). Treatment codes are: CT = conventional tillage, STC = strip-till with cultivating vegetation between-rows, and STM = strip- till with mowing vegetation between rows.

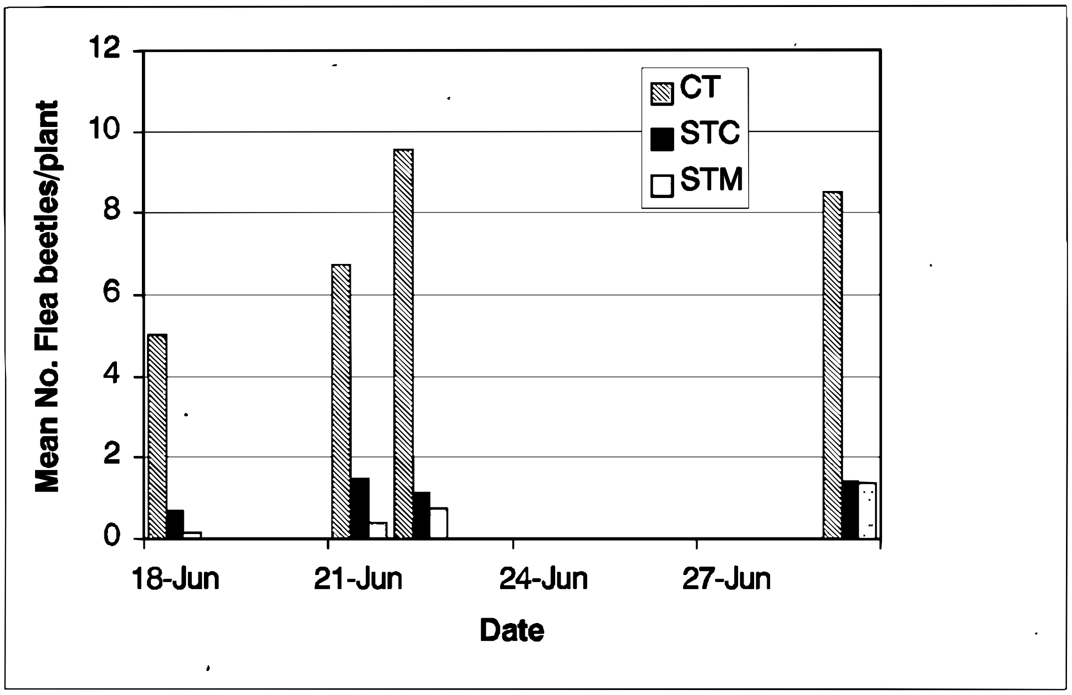

Table 1. Cover crop biomass, nitrogen accumulation, and C:N ratio, sampled May 13, 1999.

Cover crop	Total Biomass (kg/ha)	%N	Total N (kg/ha)	C:N
Barley treatment				
Barley	**1664**	**1.2**	**19**	**40**
Vetch	**2119**	**3.5**	**73**	**13**
Phacelia	**549**	**1.1**	**6**	**38**
Triticale treatment				
Triticale	**708**	**1.6**	**11**	**28**
Vetch	**2015**	**3.5**	**71**	**13**
Phacelia	**703**	**1.1**	**8**	**38**

Table 2. Effects of tillage and cover crops on soil nitrate levels, sampled July 14, 1999.

Treatment	In-row	Between -row
	Soil nitrate (ppm)	
CT-B a	7.4	8.4
CT-T b	7.2	9.0
ST-C-B c	7.1	7.4
ST-C-T d	6.1	7.1
ST-M-B e	9.5	8.1
ST-M-T f	7.3	6.7
***Treatments pooled by tillage treatment*:**		
CT g	7.3	8.7
ST-M h	8.4	7.4
ST-C i	6.6	7.2
Treatments pooled by cover crop:		
Barley	8.0	8.0
Triticale	6.9	7.6

a-conventional till in barley, b-conventional till in triticale, c-strip till plus cultivation in barley, d-strip till plus cultivation in triticale, e- strip till plus mow in barley, f-strip till plus mow in triticale, g-conventional till, h-strip till plus mow, I-strip till plus cultivate

Table 3. Effects of tillage and cover crops on percent nitrogen of broccoli leaf tissue.

Treatment	July 13, 1999	July 28, 1999
	%N	
CT-B a	5.2	3.6
CT-T b	4.8	3.7
ST-C-B c	3.9	3.5
ST-C-T d	3.6	3.2
ST-M-B e	4	3.4
ST-M-T f	3.8	3.5
Treatments pooled by tillage treatment:		
CT g	5	3.7
ST-M h	3.7	3.5
ST-C i	3.9	3.4
Treatments pooled by cover crop:		
Barley	4.4	3.5
Triticale	4.1	3.5

a-conventional till in barley, b-conventional till in triticale, c-strip till plus cultivation in barley, d-strip till plus cultivation in triticale, e- strip till plus mow in barley, f-strip till plus mow in triticale, g-conventional till, h-strip till plus mow, I-strip till plus cultivate

Table 4. The effect of tillage and cover crop treatments on grade and number of broccoli heads per plot.

Treatment	#1 Grade	#2 Grade	Total #1's and #2's	Culls
CT-B a	112	15	128	3
CT-T b	114	14	128	2
ST-C-B c	105	22	127	3
ST-C-T d	111	18	129	2
ST-M-B e	100	21	120	2
ST-M-T f	105	30	135	2
Treatments pooled by tillage treatment:				
CT g	113	15	128	2
ST-M h	108	20	128	2
ST-C i	102	26	128	2
Treatments pooled by cover crop:				
Barley	105	19	125	2
Triticale	110	21	130	2

a-conventional till in barley, b-conventional till in triticale, c-strip till plus cultivation in barley, d-strip till plus cultivation in triticale, e- strip till plus mow in barley, f-strip till plus mow in triticale, g-conventional till, h-strip till plus mow, I-strip till plus cultivate

Table 5. The effect of tillage and cover crop treatments on broccoli yields (kg/ha).

Treatment	#1 Grade	#2 Grade	Total #1's and #2's	Culls
CT-B a	9760	1555	11312	149
CT-T b	10089	1604	11680	181
ST-C-B c	7687	1975	9669	234
ST-C-T d	7599	1370	8967	173
ST-M-B e	7638	1811	9447	134
ST-M-T f	7455	2726	10180	161
Treatments pooled by tillage treatment:				
CT g	9924	1579	11501	165
ST-M h	7648	1672	9318	204
ST-C i	7547	2269	9813	148
Treatments pooled by cover crop:				
Barley	8365	1780	10143	173
Triticale	8381	1900	10279	172

a-conventional till in barley, b-conventional till in triticale, c-strip till plus cultivation in barley, d-strip till plus cultivation in triticale, e- strip till plus mow in barley, f-strip till plus mow in triticale, g-conventional till, h-strip till plus mow, I-strip till plus cultivate

Table 6. Insect contamination of broccoli heads at harvest, 1999. Values are means of 4 replicates, 10 plants per replicate ± s.e.

Tillage treatment[a]	Cover crop[b]	Cabbage aphid	Cabbage looper	Imported cabbage worm	Diamond back moth
CT	B	0.30 ± 0.25	0.03 ± 0.03	0.58 ± 0.13	0.13 ± 0.05
CT	T	0.65 ± 0.46	0.03 ± 0.03	0.78 ± 0.14	0.15 ± 0.08
ST-C	B	0.38 ± 0.30	0.00[c]	0.73 ± 0.15	0.18 ± 0.06
ST-C	T	0.20 ± 0.09	0.03 ± 0.03	0.60 ± 0.14	0.13 ± 0.05
ST-M	B	0.60 ± 0.45	0.03 ± 0.03	0.80 ± 0.18	0.08 ± 0.04
ST-M	T	0.10 ± 0.06	0.00	0.78 ± 0.17	0.20 ± 0.10

[a]Tillage treatments are: CT = conventional tillage, ST-C = strip-till with cultivation of between-row vegetation, and ST-M = strip-till with mowing of between-row vegetation.
[b]Cover crops include: B = 'Steptoe' barley and T = 'Celia' triticale.
[c]Standard errors were not calculated when mean values were zero.