

Organic Amendment and Tillage Effects on Vegetable Field Weed Emergence and Seedbanks¹

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Abstract: Evaluations of the effects of minimum tillage vs. conventional tillage and the effects of organic amendments (cover crops and compost) vs. no organic amendments were conducted in a California vegetable field. Weed densities were monitored, and soil samples were taken to measure the effects of the treatments on weed seedbanks and microbial biomass over a 24-mo period. Reduced tillage increased the density of shepherd's-purse in the upper soil layer (0 to 15 cm) of the soil seedbank compared with conventional tillage. Evidence is presented that suggests relationships between organic amendments, weed population reductions, and increases in soil microbial biomass: (1) shepherd's-purse emergence and seedbank densities were lower in the organic amendment plots, (2) microbial biomass was nearly always higher in the organic amendment plots, and (3) significant negative correlations between microbial biomass and burning nettle and shepherd's-purse emergence densities were found. These results suggest that organic matter addition may lead to reduced weed emergence.

Nomenclature: Burning nettle, *Urtica urens* L. #³ URTUR; shepherd's-purse, *Capsella bursa-pastoris* L. Medik. # CAPBP.

Additional index words: Alternative weed management, compost, cover crop, microbial biomass carbon, soil amendments, CAPBP, URTUR.

INTRODUCTION

Improved cultural methods of weed control for vegetable crops would benefit both conventional and organic producers. Development of improved cultural methods of weed control for vegetable crops will require a better understanding of weed ecology in vegetable production fields. Little work has been done on the ecology of weeds and soil seedbanks in intensive year-round vegetable production systems.

High fuel costs and the need for soil conservation have prompted the development of conservation tillage production methods for vegetables (Gaskill et al. 2000; Herrero et al. 2001). Benefits of reduced tillage include less fuel use, reduced soil erosion, and water conservation (Coolman and Hoyt 1993). The adoption of reduced tillage corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) production systems has been associated with most weed seeds remaining near the soil surface (Ball 1992; Schreiber 1992). In contrast, weed seeds in conventional

tillage systems are more evenly distributed throughout the plow layer. Reduced soil tillage has also resulted in shifts in weed communities away from large-seeded weeds that germinate from relatively deep in the soil, such as velvetleaf (*Abutilon theophrasti* Medik.), toward small-seeded weeds that germinate from shallow layers in the soil, such as giant foxtail (*Setaria faberii* Herrm.) (Buhler 1995). It is not known if reduced tillage in intensive vegetable production systems will cause changes in the seedbank.

Crop diversity, intensive tillage, high nutrient and pesticide inputs, use of organic amendments, and year-round cropping are typical of coastal vegetable production in California (Jackson et al. 1993). The high intensity of tillage associated with vegetable cropping systems has raised the alarm among some who fear that soil quality may suffer; therefore, many vegetable growers are now using cover crops in their crop rotation sequence to maintain soil quality (Wyland et al. 1996). The value of cover crops includes reduced nitrate leaching, increased soil organic matter, higher soil microbial activity, and nitrogen contribution to the subsequent crop. Other means of maintaining high soil quality include the addition of manures and composts (Hartz et al. 2000). The effects of these organic amendments on the ecology of

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³ Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

weed seedbanks in intensively managed vegetable fields are not well understood.

High soil moisture and organic matter have been associated with weed seed degradation in muck soils (Lewis 1973). Shem-Tov et al. (2002) found an inverse relationship between the germination of Ward's weed [*Carriechtera annua* (L.) DC.] seed and soil organic matter in the soil crust of desert ecosystems in Israel. The accumulation of organic matter content and the high levels of biological activity near the soil surface, associated with reduced tillage, are thought to favor degradation of ungerminated weed seed (Cardina et al. 1991; Kremer 1993). After seed germination, i.e., at the seedling establishment stage, mortality is primarily due to deleterious rhizobacteria, and bacterial or fungal rots. Soil microbe-induced weed mortality may occur in the seed and seedling stage (Kennedy 1999). Most biological control agents that have been developed to control weeds do so by infecting the weed seedling rather than the seed. However, little is known about the relationships between weed seedbank persistence, soil microbes, and soil organic matter.

Organic matter inputs in the form of cover crops and compost are used primarily to improve soil quality (Jackson et al., in press; Wyland et al. 1996). It is not known if the addition of these organic inputs may favor microbes that degrade weed seed or weed seedlings. The use of organic inputs may provide a cultural method to manage weeds, but if this is so, their effects on weeds must be better understood.

One hypothesis is that reduced tillage for a 2-yr period may increase weed seedbank densities in the upper seedbank compared with conventional levels of tillage. A second hypothesis is that addition of organic amendments to the soil supports increased soil microbial biomass and sometimes may be associated with lower weed densities, by either affecting weed seed mortality or seedling emergence, i.e., germination. The objective of this on-farm research was to monitor the effect of soil organic amendment and reduced tillage on soil microbial biomass carbon and weed biology in an intensively managed vegetable field.

MATERIALS AND METHODS

Soils and Management Practices. The study site was established in April 1998 in an 8.3-ha field site near Salinas, CA. The field had been in long-term use for cool-season vegetable production, with typically two crops per year of broccoli (*Brassica oleracea* L. var. *italica* Plenck (Group Italica), celery [*Apium graveolens*

L. var. *dulce* (Mill.) Pers.], lettuce (*Lactuca sativa* L.), or spinach (*Spinacia oleracea* L.). In 1996 lettuce and celery crops were produced, and in 1997 two lettuce crops were produced. Broccoflower[™] (cauliflower [*Brassica oleracea*] L. var. *botrytis* L. [Group Botrytis] × broccoli hybrid) was established in December 1997 and harvested just before trial initiation in April 1998. The crops were grown on 1-m-wide raised beds. The soil type was a Salinas silt loam (fine-loamy, mixed thermic Pachic Haploxerolls). The field was divided into four blocks (replicates) of approximately 2 ha each, equipped with independent surface-drip irrigation systems. Each block was divided into four 0.5-ha plots, one for each treatment, and arranged in a randomized complete block design. The treatments included in each block were (1) minimum tillage with added organic amendments, (2) minimum tillage with no added organic amendments, (3) conventional tillage with added organic amendments, and (4) conventional tillage with no added organic amendments.

The conventional tillage treatment used the same tillage practices that are typically used in the Salinas Valley, i.e., subsoiling, disking, raised-bed formation, cultivation with a rolling cultivator, and bed shaping (Ryder 1999). Raised-bed formation refers to the "listing" of a flat field into raised 1-m-wide beds, whereas "bed shaping" occurs after listing and refers to the shallow tillage required to shape the bed and form a fine seed bed. The maximum depth of tillage was approximately 50 cm. Raised beds were completely tilled under and re-formed between each crop cycle. The minimum tillage treatments used the "Sundance" system. The Sundance⁴ implement is designed as a single-pass implement that uses tillage tools, such as disk blades and shovels, to incorporate crop residues. The Sundance tills the raised bed while leaving it intact. The Sundance tills to approximately 20 cm, and no subsoiling was done in these treatments. A rolling cultivator and bed shapers were then used to prepare the minimum tillage beds for planting. One major difference between conventional tillage and minimum tillage is that the beds are left in place during tillage operations in minimum tillage, whereas they are removed and then rebuilt before crop planting in conventional tillage. Another difference is that minimum tillage only penetrates 20 cm, whereas conventional tillage penetrates up to 50-cm depth. During each vegetable cropping cycle, shallow cultivation was performed for weed control in all treatments. Weed management in the vegetable crops was based on cultivation, hand weeding,

⁴ Sundance disk, Arizona Drip Systems, Coolidge, AZ 85228.

Table 1. Schedule of management events during the 2-yr on-farm study. Amendment and no amendment indicate with and without cover crop and compost addition, respectively.

Date	Minimum tillage		Conventional tillage	
	Amendment	No amendment	Amendment	No amendment
1998				
April	Compost	Minimum tillage	Compost	Disk, chisel and form beds
July	Compost	Minimum tillage	Compost	Disk, subsoil, chisel
August	Plant cover crop	Fallow	Compost	Plant cover crop
September	Minimum tillage		Disk cover crop	Fallow Disk
1999				
January		Minimum tillage		Cultivate, form beds
May		Minimum tillage		Disk, subsoil, chisel
June		Minimum tillage		Cultivate, form beds
September	Compost	Minimum tillage	Compost	Disk, subsoil, chisel
	Compost	Minimum tillage	Compost	Cultivate
November	Plant cover crop	Fallow	Plant cover crop	Fallow
	Minimum tillage		Disk cover crop	Disk
			Subsoil, chisel, form beds	

and herbicides. The herbicide used in lettuce crops was pronamide applied at 1.12 kg ai/ha, and in broccoli DCPA was applied at 5.9 kg ai/ha. The herbicides were applied as 12-cm bands centered over the broccoli or lettuce seed lines. The timing of events is listed in Table 1.

Organic amendment treatments received compost applications twice per year and a single rye (*Socale cereale* L.) cover crop, cv. ‘Merced’, that was planted in August or September in both 1998 and 1999 (Table 1). Materials included in the compost were municipal yard waste (30%), salad packing plant waste (5%), manure, clay, finished compost, and baled straw (65%). Compost maturation took place over an 8- to 10-wk period, when it was turned 12 to 15 times and maintained at 60% moisture with an internal temperature of 57 to 71 C. The carbon–nitrogen ratio of the compost was approximately 15. Compost was applied at 9 metric tons/ha in April and July 1998 and in June and September 1999. The compost applied at 9 metric tons/ha was approximately 1 mm thick in the field. The compost was disk incorporated in the conventional tillage system or incorporated using the Sundance in the minimum tillage system. Rye cover crops were grown during August to September 1998 and September to November 1999. Timings of cover crop production and compost application were dictated by availability of the field during the intervals between cash crop production. Both cover crops were flail mowed before anthesis and incorporated with conventional tillage or the Sundance system. No weed control operations were conducted in the cover crops while they

were growing because they were broadcast seeded and could not be cultivated. Herbicides were not used in the cover crops to avoid the potential for herbicide injury in subsequent vegetable crops. Because compost and cover crop residues were incorporated with tillage, no mulch layer formed on the soil surface. Plots without cover crops (no amendment) were left fallow and shallow tilled as needed to prevent weed establishment. The no-amendment treatments received only vegetable crop residues and no other form of organic amendment. The lettuce crop dry weights were 2,410 to 4,250 kg/ha, and the broccoli dry weights were 6,050 to 6,440 kg/ha.

During the course of the study, four vegetable plantings were made. In May 1998, crisphead lettuce (cv. ‘Champ’) was planted in all the blocks. Crisphead lettuce was again planted in January 1999. Because the grower chose the crop varieties and planting dates, the blocks were not always planted with the same variety or on the same date. Blocks 1 and 2 were planted with ‘Titan’, and blocks 3 and 4 were planted with ‘Coastal’. Lettuce ‘Pacific’, a crisphead variety, was planted in June 1999 in all the blocks. Broccoli (cv. ‘Legacy’) was planted in blocks 3 and 4 in November 1999, and blocks 1 and 2 were planted in December 1999. All plantings were direct seeded and thinned to the desired stand approximately 4 wk after planting.

The cover crops and vegetable crops were germinated and established with sprinkler irrigation. The cover crops were maintained with sprinkler irrigation as required during dry weather, but surface drip irrigation was used in the vegetable crops from the time of thinning until

harvest. Surface drip irrigation was applied two to three times a month from a single-drip irrigation tape in the center of the bed. Drip tapes were removed at each harvest date. All plots were irrigated while under lettuce or broccoli production. However, during the time of cover crop production, only the organic amendment plots were irrigated.

Band applications of 5:25:25 fertilizers were made at 336 kg/ha before planting broccoli and lettuce. Ammonium sulfate at 336 kg/ha was also applied before planting broccoli. All band fertilizer applications were injected into the beds. After the vegetable crops were thinned, one to four applications of 473 to 946 L/ha of a 20% ammonium nitrate solution were applied through the drip irrigation system. The entire field received the same fertilizer applications. Nitrogen fertilizer inputs for the vegetable crops were 150 kg/ha (1998 lettuce), 95 kg/ha (first 1999 lettuce), 126 kg/ha (second 1999 lettuce), and 166 kg/ha (2000 broccoli). Soil moisture and physical characteristics of the soil during the study period are reported in a companion article (Jackson et al., in press).

Soil Sampling and Analysis. Soil characteristics were determined from the < 2-mm-soil fraction from the 0- to 15-cm depth at the beginning of the study in April 1999. Eight samples per replicate were bulked, and each replicate was analyzed separately. Soil pH was 7.0, cation exchange capacity was 27.6, total carbon was 1.44%, total nitrogen was 0.16%, and organic matter was 2.47%. Particle size distribution was 28% sand, 52% silt, and 20% clay. Soil analyses were determined by the Division of Agriculture and Natural Resources Analytical Laboratory at the University of California at Davis.

Soil cores for the purpose of sampling microbial biomass were taken at the time of vegetable crop harvest or at the time of cover crop mow down: July 19 and September 14, 1998; May 10, August 17, and October 31, 1999; April 3 (blocks 3 and 4 only) and April 24 (blocks 1 and 2 only), 2000. A total of 32 samples were taken from within 2- by 50-m subplots, which were sufficiently large so that recoring of the same location more than once during the course of the study was avoided. These soil cores were taken in the planting line and separated into 0- to 15- and 15- to 30-cm-depth increments. These core samples were put on ice immediately, and extractions were initiated 6 to 12 h after sampling. Two of the 0- to 15-cm cores per plot were bulked. From the 0- to 15-cm cores, subsamples of 50 g were taken for determination of microbial biomass carbon, using the fumigation extraction technique of Brookes et al. (1985),

and for dichromate digestion for carbon content (Vance et al. 1987).

Twenty soil cores were taken in each subplot (see above) on April 17, 1998; May 4, 1999; and March 24, 2000 for the purpose of sampling the weed seedbank. Each 2.5-cm-diam core was partitioned into 0- to 15- and 15- to 30-cm sections. The 20 soil cores from within the 0- to 15-cm or 15- to 30-cm sections were pooled by subplot, and the cores were placed in greenhouse trays, watered daily, and allowed to incubate for approximately 2 mo (Feast and Roberts 1973). The emerging weeds were identified, counted, and removed monthly. At the end of 2 mo the trays were allowed to dry in preparation for elutriation. Weed seeds were extracted from all the samples by using a 60-mesh-screen (opening area of 0.048 mm²) custom-built elutriator previously described by Battista (1998). After air drying, the elutriated samples were sieved through a 12-mesh screen (opening area of 4.8 mm²) to remove gravel. The gravel was discarded, and then a salt floatation procedure similar to that described by Malone (1967) was used to separate the weed seed from the remaining soil. The floating fraction was collected, spread in a thin layer, and inspected for seeds under a $\times 20$ dissection microscope. Seed viability was determined using a modified version of the procedure described by Ball and Miller (1989). Seeds that did not collapse under pressure by a forceps were split open with the forceps to expose the embryo. Those that showed a firm, whitish embryo were considered viable and were recorded by species. The total number of viable weed seeds per soil sample was determined by adding the total number of weed seedlings that emerged in the greenhouse trays during 2 mo of incubation to the total number of viable ungerminated weed seeds by species that were extracted from each soil sample.

Weed density counts in the field were taken in each cropping cycle, and if possible, the counts were timed to occur before cultivation or hand-weeding operations. It was not possible to take weed density counts in the no-amendment plots in November 1999 because these plots were not irrigated during the time of cover crop production and there was no weed emergence on account of dry weather. Precipitation, air, and 15-cm-soil temperatures for the study period were recorded by the CIMIS⁵ north Salinas weather station approximately 7 km from the site (Table 2).

⁵ CIMIS weather data for select California locations are available online at <http://www.ipm.ucdavis.edu/weather/weather1.html>.

Table 2. Total monthly precipitation (mm), and average monthly air and 15-cm-soil temperatures at Salinas, CA, during the study period.^a

Month	Precipitation	Air temperature		Soil temperature	
		Maximum	Minimum	Maximum	Minimum
	mm	C			
April 1998	44.2	17.2	7.2	12.6	11.8
May 1998	34.4	18.2	9.1	16.2	14.5
June 1998	5.8	18.9	11.8	19.1	16.3
July 1998	0	19.1	12.3	20.2	17.2
August 1998	5.6	20.4	12.8	21.2	18.8
September 1998	0.8	20.0	12.6	20.8	18.7
October 1998	20.3	19.5	7.8	17.6	15.2
November 1998	60.2	16.8	6.4	13.9	12.3
December 1998	19.5	14.3	2.0	9.9	8.7
January 1999	65.7	16.1	4.7	10.7	9.4
February 1999	85.8	15.0	4.5	10.8	9.5
March 1999	55.6	14.3	4.8	11.3	10.4
April 1999	35.0	16.3	6.0	13.7	12.4
May 1999	1.3	16.0	7.6	16.9	15.3
June 1999	1.0	17.8	9.9	19.2	17.5
July 1999	0	18.4	11.6	20.8	19.2
August 1999	0	19.6	12.2	21.2	19.8
September 1999	0	19.5	11.4	20.1	19.0
October 1999	0	21.8	8.9	18.7	17.5
November 1999	22.6	18.4	7.4	15.4	14.2
December 1999	2.0	17.5	3.0	11.1	9.7
January 2000	139.8	15.3	6.1	11.7	10.8
February 2000	145.4	16.2	8.0	12.8	12.0
March 2000	53.0	16.4	5.6	12.6	11.8
April 2000	16.0	18.6	7.2	15.0	14.0

^a Data were recorded by the CIMIS "North Salinas" weather station.

Data Analysis. The SAS PROC GLM⁶ procedure was used to estimate the main effects of tillage and organic amendments on weed density and soil microbial biomass carbon. The factors organic amendment, tillage, and organic amendment by tillage interaction were tested in the model. The effects of tillage on seedbank densities at the 0- to 15- and 15- to 30-cm depths were also tested using SAS PROC GLM. The factors tested in the model were depth, tillage, organic amendment, sample time, depth by tillage, depth by tillage by sample time, and tillage by amendment by sample time. Data were pooled across sample dates if the tillage by amendment by sample time interaction was not significant. Fisher's LSD was used for mean separation as necessary. The relationships between soil microbial biomass carbon at all sample dates and weed emergence densities or between soil microbial biomass carbon and weed seedbank densities were tested using the SAS PROC CORR Spearman Rank correlation procedure. Weed density and seedbank data were $\log(Y + 1)$ transformed before analysis to normalize variances using the procedure described in Steele and Torrie (1980). Because it is not possible to convert standard errors to original units after transformation (Steele and

Torrie 1980), weed density and seedbank data are presented without standard errors. Transformation of the microbial biomass data was not necessary and was not performed.

RESULTS AND DISCUSSION

Weed Densities and Weed Seedbanks. Predominate weeds at the study site throughout the year were burning nettle and shepherd's-purse. Shepherd's-purse in a mixed population of annual weeds can cause significant yield reduction in lettuce (Fennimore and Umeda 2002). Another effect of these weeds in vegetables is the increased cost of hand weeding (Fennimore et al. 2001; Haar et al. 2001).

Addition of organic amendments was associated with reduced burning nettle densities in December 1999 and reduced shepherd's-purse densities in December 1998 and July 1999 (Table 3). The effects of organic amendments were not consistent throughout the study period. The reasons for this inconsistency may be weed variability within the subplots, and weed control inputs such as herbicides and cultivation that likely reduced the differences among treatments. Seasonal temperature variations may contribute to variations in the effects of organic amendments (Table 2). Other factors include differences in the relative competitive abilities of the crops: broccoli, lettuce, and rye (cover crop). Seasonal variation in weed emergence may also have contributed to the lack of consistent effects of organic amendments. In other research, we have found that burning nettle and shepherd's-purse emerge the year round in the Salinas Valley; however, seasonal density fluctuations do occur (Fennimore and Shem-Tov 2002; Shem-Tov and Fennimore 2002). Whereas organic amendments resulted in significant reductions in shepherd's-purse emergence only in December 1998 and July 1999, weed densities were always lower (except for burning nettle in July 1999) in the amended plots than in the unamended plots (Table 3). Organic amendments were associated with reduced shepherd's-purse seedbank densities in the May 1999 and March 2000 pooled seedbank data (Figure 1).

During the fall there was greater potential for seed set in the organic amendment plots, where some weeds were present in the cover crop, than in the no-amendment plots, where no weeds were able to grow during the fallow periods because of cultivation and lack of moisture (Tables 2 and 3). Burning nettle densities in both 1998 and 1999 cover crops ranged from 2.7 to 4.3 seedlings/m², and shepherd's-purse densities ranged from 8.8 to 35.6 seedlings/m². Gallandt et al. (1998) observed that

⁶ SAS for Windows, version 8.0, Statistical Analysis Systems Institute, Cary, NC 27511.

Table 3. Effect of soil management system and tillage system on burning nettle and shepherd's-purse plant mean densities at four sample dates during 1998 and 1999.

Soil management system ^a	Tillage system	December 1998	July 1999	August 1999	December 1999
		no./m ²			
Burning nettle					
Amended	Minimum	2.0	2.2	0.7	2.2
Unamended	Minimum	7.4	5.8	0.9	4.9
Amended	Conventional	4.3	5.8	1.3	1.3
Unamended	Conventional	6.9	4.9	1.8	5.8
ANOVA					
Soil amendment (SA)		NS	NS	NS	**
Tillage (T)		NS	*	NS	NS
SA × T		NS	NS	NS	*
Shepherd's-purse					
Amended	Minimum	32.9	31.3	10.1	37.6
Unamended	Minimum	116.5	94.1	19.9	50.1
Amended	Conventional	31.1	42.7	2.0	10.3
Unamended	Conventional	101.7	87.2	3.8	55.0
ANOVA					
Soil amendment		***	**	NS	NS
Tillage		NS	NS	*	NS

^a Amended plots received cover crop and compost amendments; unamended plots received no organic matter other than cash crop residues.

*, **, ***: Significant at P < 0.05, 0.01, 0.001, respectively.

the use of cover crops was associated with reductions in common lambsquarters (*Chenopodium album* L.) infestation in their potato crop, and they hypothesized that reduced weed seed set during the time of cover crop production before the potato crop contributed to reduced weed populations. In our study, however, dry soil and tillage in the no-amendment treatments kept these plots weed free during the fallow period. Therefore, weed seed set in these plots would have had to occur during the time of lettuce and broccoli production. Other than during the period of cover crop production in the organic amendment plots, weed control inputs such as cultivation, herbicides, and hand weeding were the same across the entire study. Thus, the reduction in weeds in the organic amendment plots is most likely due to indirect effects after addition of cover crops and compost rather than to direct competition between weeds and cover crops.

There is some evidence that tillage affected weed populations. Conventional tillage was associated with higher burning nettle densities in July 1999 and lower shepherd's-purse densities in August 1999 (Table 3). The soil amendment by tillage interaction was significant for burning nettle in December 1999, and the data show that differences between the amendment and no-amendment densities were greater in the conventional tillage plots than in the minimum tillage plots (Table 3). The depth by tillage interaction for shepherd's-purse seed banks was significant for the pooled 1999 and 2000 densities

(Figure 2). These data suggest that in the 0- to 15-cm soil layer, reduced tillage favored higher shepherd's-purse seedbank densities more than did conventional tillage. This time period may not have been long enough for differences in the upper and lower soil layers to develop for burning nettle, because of the relatively low seedbank densities for that species. Schreiber (1992) found that tillage effects on weed seedbanks were not evident until 2 to 3 yr after the adoption of no-till farming practices.

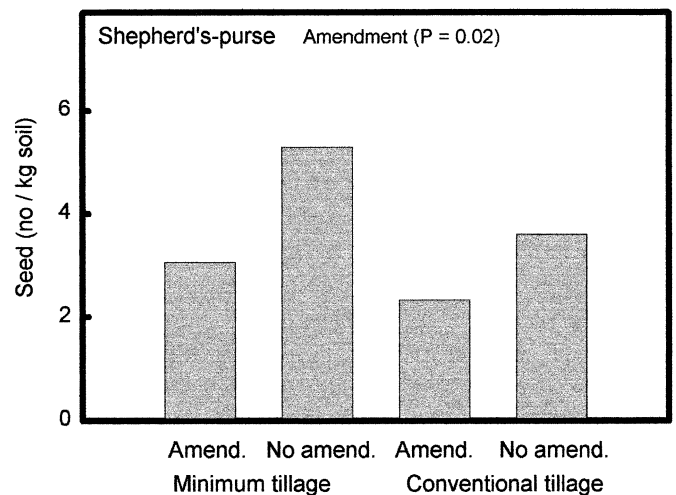


Figure 1. Pooled averages for the two dates (May 1999 and March 2000) when shepherd's-purse seedbank densities 0 to 30 cm deep were sampled. The main effect of organic amendment was significant.

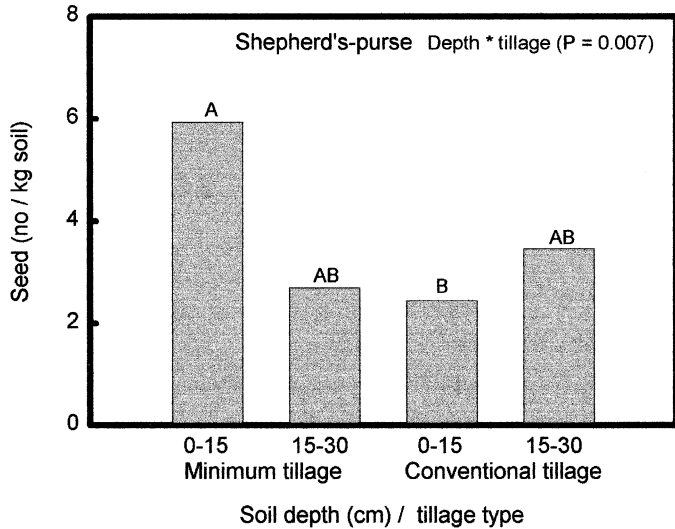


Figure 2. Pooled averages of May 1999 and March 2000 shepherd's-purse seedbank densities by depth: 0 to 15 and 15 to 30 cm. The depth by tillage interaction was significant.

Soil Microbial Biomass and Correlations with Weeds.

From September 1998 until April 2000 (with the exception of August 1999, data not shown), organic amendments were associated with higher levels of soil microbial biomass carbon than were no-amendment plots (Table 4). In February 1999, tillage treatments responded differently to soil amendment. The data indicate that the response of microbial biomass to organic amendments was greater in conventional tillage than in minimum tillage. Only on the last sampling date, April 2000, was a significant tillage effect observed; minimum tillage was associated with higher soil microbial biomass carbon. Overall, microbial biomass was affected little by tillage in this study.

The degree to which microbial biomass and weed emergence varied together was evaluated. There was a negative correlation between the April 2000 microbial biomass and the December 1999 burning nettle and

shepherd's-purse emergence, $r = -0.83$ and -0.90 , respectively. Similarly, a negative correlation of $r = -0.67$ was found between the August 1999 microbial biomass and the December 1999 shepherd's-purse densities. These periods of negative correlation between microbial biomass carbon and weed emergence occurred during winter (December 1999), when weed densities were highest (Table 3). The reasons for the correlations between weed emergence in December 1999 and microbial biomass carbon in April 2000 are unclear. Perhaps they suggest that interactions between weed and soil microbe populations are only evident when examined over long time periods. Until the interactions between microbial species or complexes and weeds are better understood, the reasons may remain unclear. No relationship between microbial biomass and weed seedbank densities was found (data not shown).

The 1999 and 2000 pooled shepherd's-purse seedbank densities from the 0- to 30-cm soil layer were 36 and 42% lower in the organic amendment plots than in the no-amendment plots, respectively (Figure 1). Fellows and Roeth (1992) and Lonsdale (1993) found evidence of some reduction of seed bank viability due to pathogen attack. Seed rain was not measured; therefore, we cannot differentiate between seedbank losses to germination and losses to pathogen attack. Our data express the effect of the treatments on the seedbank rather than the effect of the treatment on distinct cohorts of seed. It is possible that low-percentage seed losses to pathogen attack in the organic amendment plots (Fellows and Roeth 1992; Lonsdale 1993) and a slightly greater weed seed production in the no-amendment plots, due to higher weed emergence densities, could explain the differences in seedbank densities.

Despite the fact that weeds had the potential to set seed for a longer period of time in the organic amendment plots, the seedbanks in the no-amendment plots

Table 4. Effect of organic amendments and tillage on microbial biomass carbon at 0- to 15-cm depth (\pm SE).

Soil management system ^a	Tillage system	September 1998	February 1999	May 1999	November 1999	April 2000
g C/g soil						
Amended	Minimum	146.2 \pm 17.6	194.8 \pm 13.0	151.3 \pm 9.2	159.7 \pm 13.2	164.8 \pm 10.3
Unamended	Minimum	95.1 \pm 11.7	128.8 \pm 9.4	96.5 \pm 10.7	129.2 \pm 20.9	116.3 \pm 6.3
Amended	Conventional	120.1 \pm 11.8	217.9 \pm 15.7	149.2 \pm 12.6	190.9 \pm 16.0	148.2 \pm 16.5
Unamended	Conventional	86.4 \pm 11.4	95.6 \pm 7.1	78.3 \pm 7.4	97.7 \pm 11.4	87.4 \pm 9.6
ANOVA						
Soil amendment (SA)		*	*	*	*	*
Tillage (T)		NS	NS	NS	NS	*
SA \times T		NS	*	NS	NS	NS

^a Amended plots received cover crop and compost amendments; unamended plots received no organic matter other than cash crop residues.

* Significant at $P < 0.05$.

were larger (Figure 1) as discussed above. This suggests that differences in weed densities between the amendment and no-amendment treatments could be due to weed seed degradation by soil microbes, differences in seedling establishment due to the presence of soil microbes that attacked weed seedlings, or both. Allelochemicals from rye cover crop incorporation in November 1999 (Table 1) may explain why nettle densities were reduced in the amended treatments in December 1999 (Table 3). However, allelochemicals do not explain the reduction in weed densities associated with the organic amendment plots at other times. Generally, allelochemicals do not persist for long in the soil environment (Duke et al. 2000; Schmidt and Ley 1999), so it seems unlikely that allelochemicals from cover crops are an explanation for reduced weed densities in the organic amendment plots.

Implications for Weed Management. We have not provided direct evidence that soil microorganisms were responsible for the reductions in weed seedling emergence observed here. However, indirect evidence suggests that increased organic matter or microbial biomass (or both) have the potential to affect weed density and the persistence of weed seedbanks (Gallandt et al. 1999). Regardless of whether allelochemicals, soil nutrients, soil microorganisms, or some other factor reduced weed densities in the organic amendment plots, further work must be undertaken to understand better the interactions between weed emergence and organic amendments in intensive vegetable production systems. Our results suggest that organic matter management, soil nutrients, and soil microbial biomass need to be considered when developing weed management strategies. For example, if high levels of organic matter can be added to a field for a sufficient period of time, it may be possible to reduce the populations of at least some weed species. The results presented here suggest that organic inputs may improve the management of burning nettle and shepherd's-purse.

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