Soil Quality Research

Organic vegetable crop systems experiment and on-farm evaluations, October 2007

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Summary:
We evaluated the effects of cover crop, amendment, and tillage strategies on soil quality in organic vegetable production. Amendment had the greatest effect across a range of soil properties. Tillage frequency affected nematode and collembola ecology. Spader tillage reduced subsurface compaction. Amendment, cover crop, and tillage all affected crop yield in at least one year.

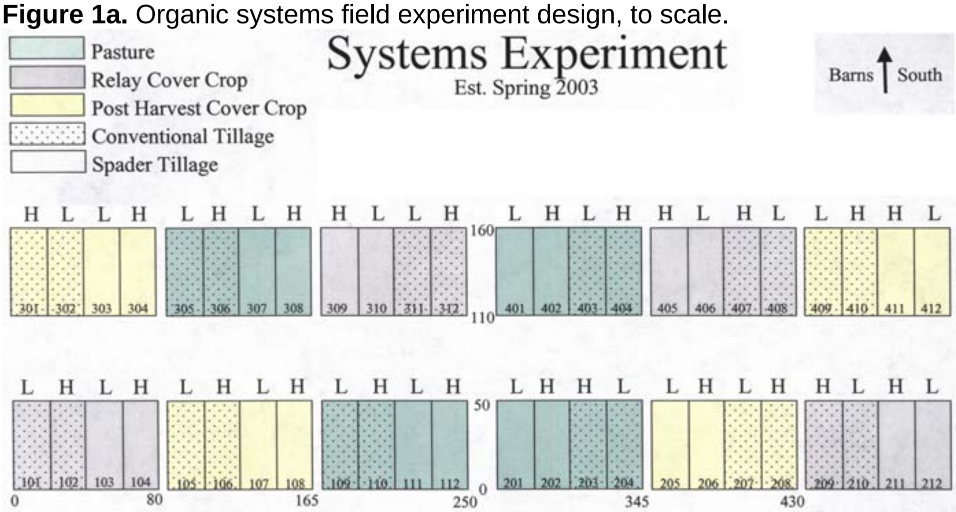
Objective:
Compare the effects intensive organic vegetable crop management systems on soil quality as measured by field and laboratory tests and field observations.

Methods:
Vegetable crop systems experiment

The vegetable crops systems experiment at WSU Puyallup was established in 2003. It compares 12 combinations of organic management systems, consisting of three cover crop treatments, two tillage treatments, and two soil amendment treatments arranged in a split-split plot design. Cover crops are the main plots, tillage is the first split and amendments the second split (Fig 1a, b). The experimental area consists of four replicate blocks, each measuring 250 x 50 ft. Main plots (cover crops) within the blocks are 80 x 50 ft. Mowed tall fescue strips buffer the treatment area. The entire field, including buffers, is organically certified and measures 570 x 210 ft. The soil is a Puyallup fine sandy loam, developed from recent alluvium in the Puyallup valley of western Washington. The surrounding area is a mosaic of annual and perennial crops, grass pastures, and wetlands.

We chose treatments based on input from farmers through focus groups, surveys, meetings, and farm visits. They represent a range of strategies of interest to organic farmers, and provide contrasts in organic carbon additions, tillage intensity, and duration of the cover crop cycle (Fig. 2). Cash crops chosen for the rotation are commonly grown on local organic fresh market farms and cover a range in growth habits and management requirements.

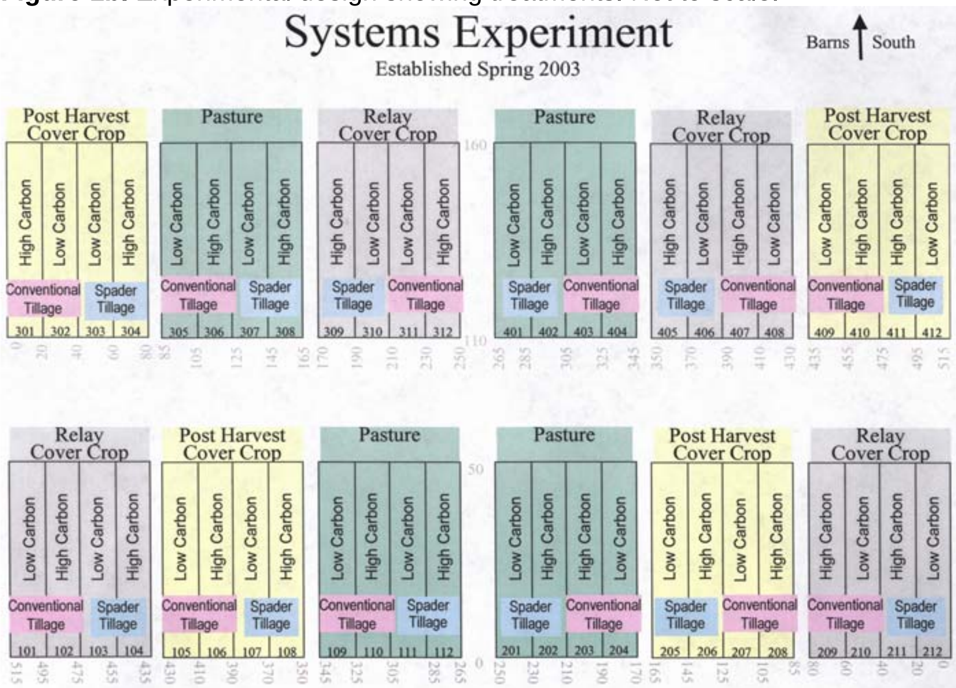
Figure 1a. Organic systems field experiment design, to scale.



Cover crop treatments include 1) a fall-seeded cereal rye-hairy vetch mix, 2) relay-intercropped hairy vetch or red clover planted into the cash crop, and 3) a short-term annual ryegrass-perennial ryegrass-red clover pasture (ley) crop. The value of these cover crops includes N fixation, ground cover, weed suppression, and biomass.

Relay planting offers benefits of early establishment of legumes, an N-rich green manure, and reduced tillage. Disadvantages include a

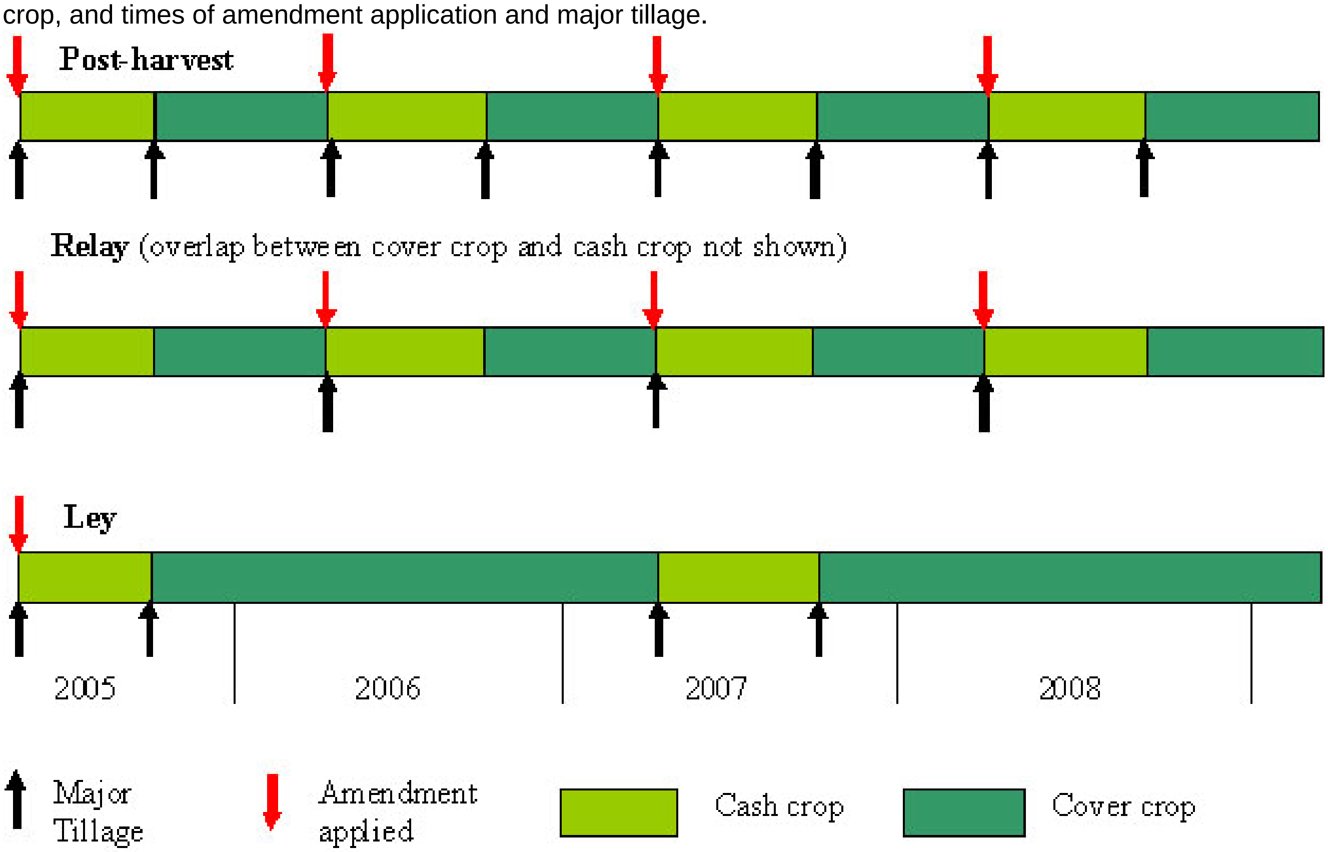
Figure 1b. Experimental design showing treatments. Not to scale.



smaller window for weed cultivation, and risk of reduced stands from crop and residue competition and winter damage.

The ley rotation provides an extended period of weed suppression and reduced tillage, and is attractive to farmers with livestock or who are not limited by land. The land is in pasture more than 75% of the cropping cycle and cash crops are planted only in alternating years. Poultry (broilers) are raised on the ley plots for 6-8 weeks during the pasture phase. We have transitioned the ley rotation into a low-input treatment, with no amendments applied since 2005.

Figure 2. Time line showing time in cash crop (from field preparation through post-harvest chopping) and cover crop, and times of amendment application and major tillage.



Organic amendments include a low-carbon treatment (broiler litter, mean total N = 3.6%; C: N = 11:1) and a high-carbon treatment (mixed on-farm compost, mean total N = 1.8%; C:N = 15:1). The broiler litter is self-heated and turned 5 times to meet organic pathogen reduction standards. The on-farm compost is actively composted for one month in an aerated static pile, followed by a 5-month curing period. Application rates ranged from 1.8 to 2.7 dry tons/acre (128 to 216 lb total N/acre) for the broiler litter and 10 to 17 dry tons/acre (440 to 580 lb total N/acre) for the on-farm compost. Rates are based on a 2-year field and laboratory assessment of available N from organic amendments (Gale et al., 2006). We did not met time-temperature requirements for pathogen reduction all years, and when that occurred, we observed 90 or 120 day waiting periods between amendment application and crop harvest, depending on the crop.

The tillage regimes are conventional tillage (plow, disc, rototill) and modified tillage (low-speed rotating spader). The spader is designed to simulate hand digging with a shovel. It can incorporate amendments and produce a seedbed in a single pass in light-textured soils.

The crop rotation for the first three years was snap bean (2003), spinach following summer cover (2004), and winter squash (2005). In 2006 and 2007, 4 rotation crops were grown in each plot each year, by dividing the plots into narrow beds, typical of those used by local organic mixed vegetable growers. The rotation across beds is: 1) double crop of spring broccoli followed by fall spinach, 2) snap bean, and 3) winter squash.

The plots in the ley treatment were in cash crops each odd-numbered growing season (2003, 05, 07) and in pasture at all other times. Table 1 shows the timing of key field activities in each of the cover crop treatments from 2003-2007.

Soil quality measurements
Aggregate stability, infiltration, and soil compaction measurements were made before planting the cash crop (2-3 weeks after incorporation of cover crops and amendments) and again in mid-season (beginning of canopy closure) each year. Samples for bulk density were collected mid season. We measured aggregate stability on composite samples from the 0 to 10 cm depth of each plot using wet sieving (4.25, 2, 1, and 0.25 mm sieves) and evaluated data as mean aggregate diameter and aggregate size histograms (Nimmo and Perkins, 2002). Soil compaction measurements were made with a Rimik recording penetrometer (9 readings per plot, 0 to 30 cm depth), and bulk density done with a hammer driven core sampler (0 to 8 cm depth, 3 per plot). Infiltration rate was measured using a simple single-ring falling-head method (Soil Quality Institute, 1999) at 5 locations/plot. Enzyme activities (dehydrogenase and b-glucosidase) (Tabatabai, 1994) and POM C (53 um + fraction; Cambardella and Elliot, 1992).were measured in samples collected before planting the cash crop and at mid-season in samples collected from the 0 to 10 cm depth.

Collembola were isolated from three replicate soil samples per plot (5 cm depth, 0.45 L per sample). Soil samples were weighed, placed in Berlese-Tullgren funnels, and collembolans extracted by heating and drying the soil, based on the method of Moldenke (1994). Collembola were identified at the family level.

Nematodes were extracted from fresh soil collected from the 0 to 15 cm depth (15 cores/plot) using a sieving-Baermann funnel procedure. Prior to routine counting and identification of nematodes in samples from experimental plots, the dominant genera at the site were identified by observing >500 individual specimens representing all treatments at 400X to 1000X with a compound microscope equipped with Nomarski DIC. Thereafter, routine analyses of experimental samples were performed by observing samples in a counting dish with an inverted microscope. The number of nematodes was determined in each sample (at 40X) and then 100 randomly chosen individuals were identified to the level of genus when possible (at 400X). The data on relative and absolute abundance of the taxa were used in construction of ecological indices as described previously (Forge et al., 2005; 2003; Ferris et al., 2001; Bongers and Ferris, 1999). Samples for collembola and nematodes were collected once in 2005 and three times (pre-plant, mid-season, and post-harvest) in 2006 and 2007 from a subset of 24 plots plus 4 areas in the grassed alleyways between plots. The pre-plant 2007 samples were collected in early spring before disturbance by amendment application and tillage.

On-farm soil quality evaluations
In 2005 we measured bulk density, aggregate stability, infiltration rate, penetrometer resistance, and texture at multiple points on each of the six cooperating farms. At two of the farms we made measurements at two separate locations under their management. We also collected composite samples for soil organic matter, pH, Bray P and exchangeable K. Each sampling location was logged into a GPS system so that we can return to the same points in subsequent years. In 2006 and 2007 we completed measurements at four of the six farms.

Table 1. Dates of key field activities in the three cover crop treatments. Puyallup Expt.

Season & Activity	Cover crop treatment		
2003 season	**Relay Cover Crop**	**Post-harvest Cover Crop**	**Pasture**
Plant snap bean	30 May	30 May	30 May
Plant cover crop	30 Jun (interseed vetch)	----	----
Harvest snap bean	5, 12 Aug	5, 12 Aug	5, 12 Aug
Incorporate residues	----	19, 28 Aug	19, 28 Aug
Plant cover crop	----	15 Sep (rye/vetch)	16 Sep (ryegrass/clover)
2004 season	**Relay Cover Crop**	**Post-harvest Cover Crop**	**Pasture**
Mow	----	(mow & mulch) 9 Apr, 7 June	(harvested) 9 Apr, 10 May, 8 June, 6 July, 26 Aug
Incorporate cover crop	29 Apr	8 July	----
Plant buckwheat 1	14 May	----	----
Incorporate buckwheat 1	23 June	----	----
Plant buckwheat 2	29 June	----	----
Incorporate cover crop & amendments	28 July	28 July (amendment only)	----
Plant spinach	5, 20 Aug	5, 20 Aug	----
Soil quality sampling	20 Aug	20 Aug	20 Aug
Harvest spinach	14 Sep, 4 Oct	14 Sep, 4 Oct	----
Plant cover crop	24 Sep (vetch)	----	26 Aug (overseed)
Incorporate residues	----	4 Oct	----
Plant cover crop	----	5 Oct (rye/vetch)	----
2005 season	**Relay Cover Crop**	**Post-harvest Cover Crop**	**Pasture**
Incorporate pasture & amendments	5-6 May	5-6 May	5-6 May
Soil quality sampling	20-24 May	20-24 May	20-24 May
Plant squash	1 June	1 June	1 June
Plant cover crop	12 July (relay vetch)	----	----
Soil quality sampling	19-25 July	19-25 July	19-25 July
Harvest squash	26 Sept	26 Sept	26 Sept
Incorporate residues	----	30 Sept	30 Sept
Plant cover crop	----	4 Oct (rye/vetch)	3 Oct (ryegrass/clover)
2006 season	**Relay Cover Crop**	**Post-harvest Cover Crop**	**Pasture**
Harvested	----	----	10 Apr, 16 May, 5 Jul, 28 Jul, 24 Aug, 11 Oct
Incorporate cover crop & amendments	12 Apr	12 Apr	----
Soil quality sampling	3,4,8,24-26 May	3,4,8,24-26 May	3,4,8,24-26 May
Transplant broccoli	11 May	11 May	----
Plant squash, snap beans	29 May	29 May	----
Chickens on pasture	----	----	12 June-19 July
Collembola and nematode sampling	14 June	14 June	14 June
Soil quality sampling	20-21 June, 5-10 July	20-21 Jun, 5-10 July	20-21 June, 5-10 July
Harvest broccoli	26 June-3 July	26 June-3 July	----
Plant cover crop	3 July (vetch in beans) (clover in squash)	----	----
Harvest beans	2, 7 Aug	2, 7 Aug	----
Plant spinach	15 Aug	15 Aug	----
Plant cover crop	8 Sept (vetch in spinach)	----	----
Harvest squash	21 Sept	21 Sept	----
Harvest spinach	28-29 Sept	28-29 Sept	----
Incorporate residues	----	2 Oct	----
Plant cover crop	----	4 Oct (rye/vetch)	----
2007 season	**Relay Cover Crop**	**Post-harvest Cover Crop**	**Pasture**
Incorporate cover crop & amendments	12 Apr	12 Apr	12 Apr
Transplant broccoli	23 May	23 May	23 May
Plant squash, snap beans	25 May	25 May	25 May
Soil quality sampling	29 May - 1 Jun, 26 Jun - 5 July	29 May - 1 Jun, 26 Jun - 5 July	29 May - 1 Jun, 26 Jun - 5 July
Plant cover crop	28 Jun (ryegrass in beans, clover in squash)	----	
Harvest broccoli	11-16 July	11-16 July	11-16 July
Harvest beans	31 July, 6 Aug	31 July, 6 Aug	31 July, 6 Aug
Plant spinach	8 Aug	8 Aug	8 Aug
Plant cover crop	5 Sept (vetch in spinach)	----	----
Harvest spinach	21 Sept	21 Sept	21 Sept
Harvest squash	24-25 Sept	24-25 Sept	24-25 Sept
Incorporate residues	----	26 Sept	26 Sept
Plant cover crop	----	27 Sept (rye/vetch)	27 Sept (ryegrass/clover)

Results and Discussion:

Vegetable crop systems experiment

Bulk density. Soils with low bulk density are generally more porous and contain more organic matter than soils with high bulk density. Bulk density measured in mid season of 2005, 2006, and 2007 was significantly lower in plots receiving the high C amendment (on-farm compost) compared with the low C amendment (broiler litter). Cover crop affected bulk density in 2004 and 2006, with higher bulk density in the ley treatment. There was no difference among cover crop treatments in 2005 and 2007, when the ley treatment was in cash crop production. In 2006 there was an interaction between cover crop and amendment, with a larger amendment effect in the relay and post-harvest treatments than in the ley treatment. This did not appear to be related to the difference in cumulative amendment rates between the ley and other treatments, because the interaction was not present in 2007. The compaction that occurs in the pasture phase of the ley treatment may have masked some of the differences from amendment in 2006. Tillage system did not affect bulk density. Amendment and cover crop effects from 2004-2007 are shown in Table 2.

Table 2. Bulk density, organic systems experiment, 2004-2007.

	2004	2005	2006	2007
	g/mL			
Cover crop				
Ley	**1.28a**	1.04	**1.21a**	0.93
Fall	**1.21b**	1.04	**1.02b**	0.92
Relay	**1.06c**	1.04	**1.00b**	0.91
Amendment				
Low C	1.19	**1.06a**	**1.11a**	**0.93a**
High C	1.17	**1.01b**	**1.04b**	**0.91b**
Interaction				
CC x amendment	NS	NS	***	NS

[1]Means within a column and treatment group followed by different letters are significantly different at P<0.05 by protected LSD.

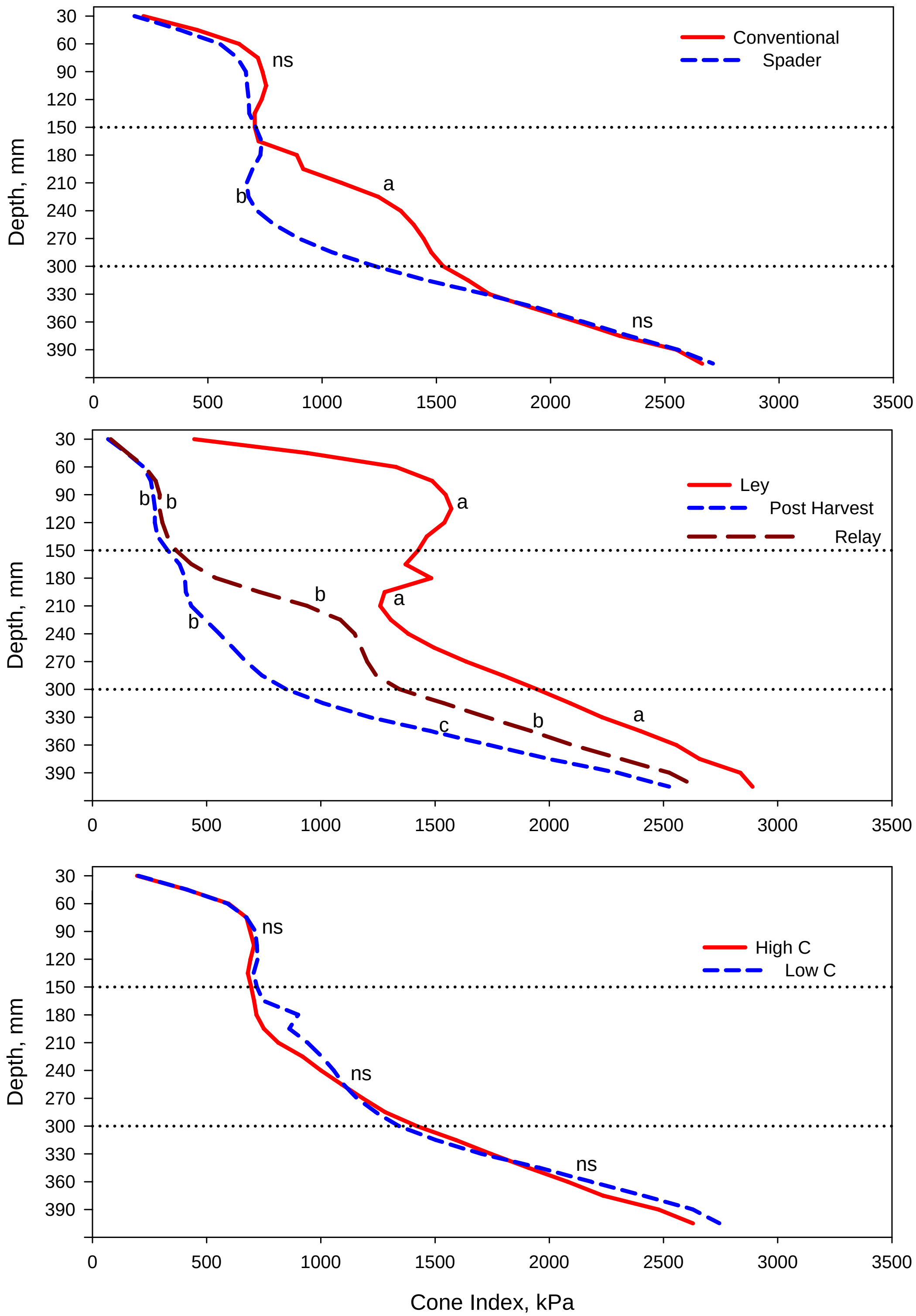
Soil compaction (0 to 40 cm depth) was measured twice each year using a recording cone penetrometer. Soils have been consistently less compact at the 15 to 30 cm depth in the plots tilled with the spader, in part because of the greater depth of tillage done by the spader. Soil in the ley treatment was significantly more compact in the upper part of the profile in 2004 and 2006 (pasture years), but not in 2005 (cash crop year). There was a cover crop x tillage interaction in 2004 and 2006. In 2004 there was no tillage effect in the ley treatment, while in 2006 there was a smaller tillage effect in the ley treatment than observed in the other cover crops. The tillage effect in the 2006 ley treatment was noteworthy, because the plots had not been tilled since the fall of 2005, indicating tillage effects persisting more than one growing season. We measured a small amendment effect in 2006, with less compaction in the high C treatment in the upper part of the profile. This was the first year that an amendment effect was seen. Fig. 4 compares tillage, cover crop, and amendment effects on compaction for the mid-season measurement in 2004, 2005, and 2006. Data were averaged over the 0-15, 15-30 and 30-40 cm depths and statistical comparisons made over those depth intervals. Results were similar for the early season measurements. Analysis of 2007 data is not complete.

Infiltration measurements were made at planting and mid season in 2005, 2006, and 2007 using a simple single ring infiltrometer with falling head. Infiltration rate was greater with the high C amendment in the spring of 2005 and 2006, but the differences were no longer significant by mid season. In 2007 the amendment effect on infiltration rate was significant in both the early and mid-season measurement, suggesting the amendment effect was persisting later into the growing season (Table 3). Cover crop treatment had no effect on infiltration rates in 2005 and 2007 when all plots were in cash crops during the growing season. The infiltration rate was much lower in the ley treatment in 2006, when it was in the pasture phase. The significant cover crop x amendment interactions in 2006 and 2007 were the result of larger amendment differences for the relay and post-harvest treatments than for the ley treatment, which received no amendments since 2005.

Aggregate stability. No differences in aggregate stability were observed among treatments analyzed through 2006. The lack of difference may reflect difficulty in improving aggregation in the fine sandy soils in our study, or may be because the technique used is not good at differentiating aggregation under the conditions of our study.

Particulate organic matter (POM) C was consistently greater in the plots receiving the high C amendment, indicating the immediate effect of amendment addition on soil C when large amounts of amendments are applied (Table 4). Neither cover crop nor tillage affected POM C.

Figure 4a. Penetrometer resistance in Puyallup systems experiment, Sept. 2004. Comparisons between conventional and spader tillage (upper), cover crops (middle), and amendments (lower). Lines within a zone with different letters are significantly different (P<0.05).



systems dec 2006 sum.JNB

Figure 4b. Penetrometer resistance in Puyallup systems experiment, July 2005. Comparisons between conventional and spader tillage (upper), cover crops (middle), and amendments (lower). Lines within a zone with different letters are significantly different (P<0.05).

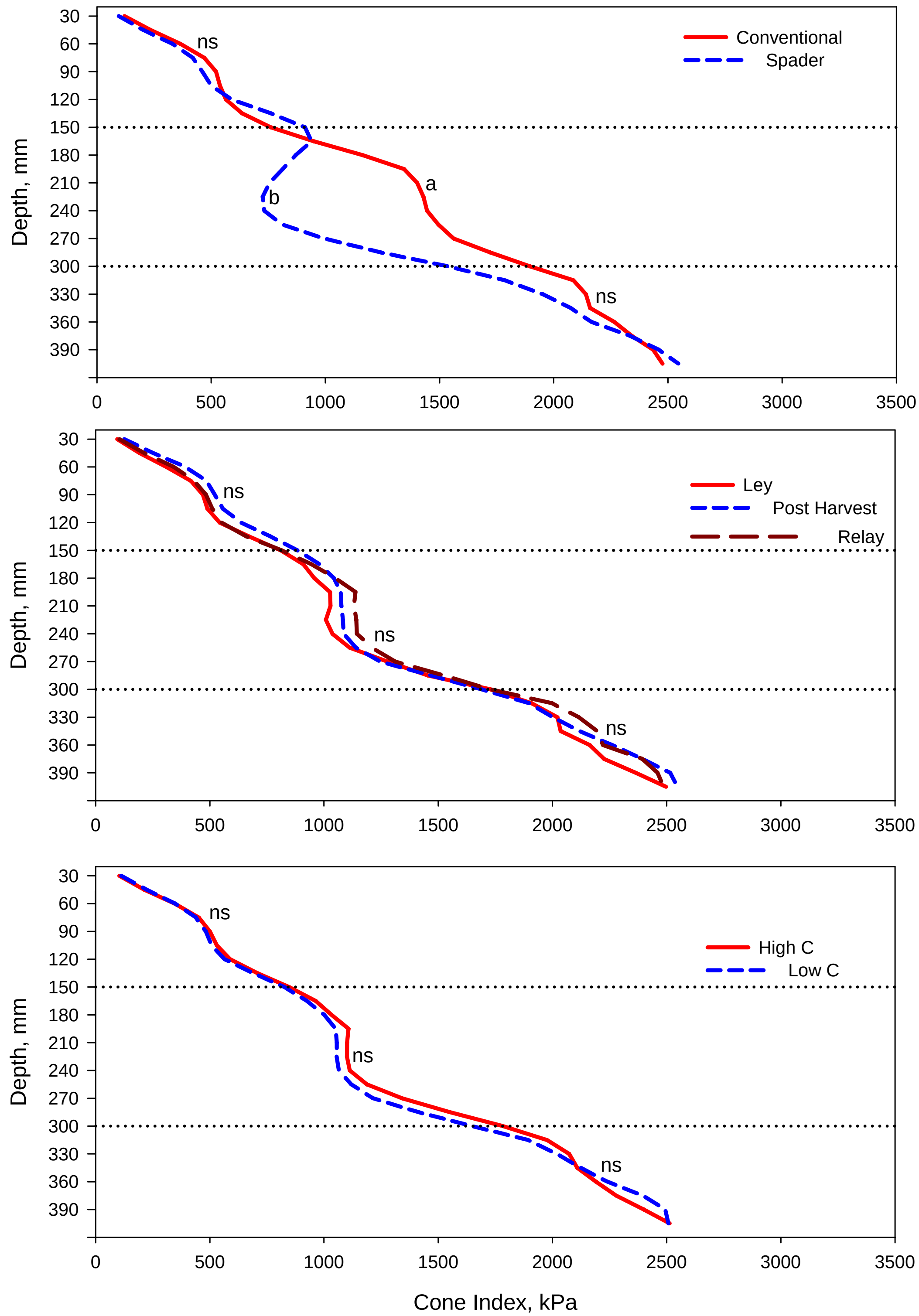


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Figure 4c. Penetrometer resistance in Puyallup systems experiment, July 2006. Comparisons between conventional and spader tillage (upper), cover crops (middle), and amendments (lower). Lines within a zone with different letters are significantly different (P<0.05).

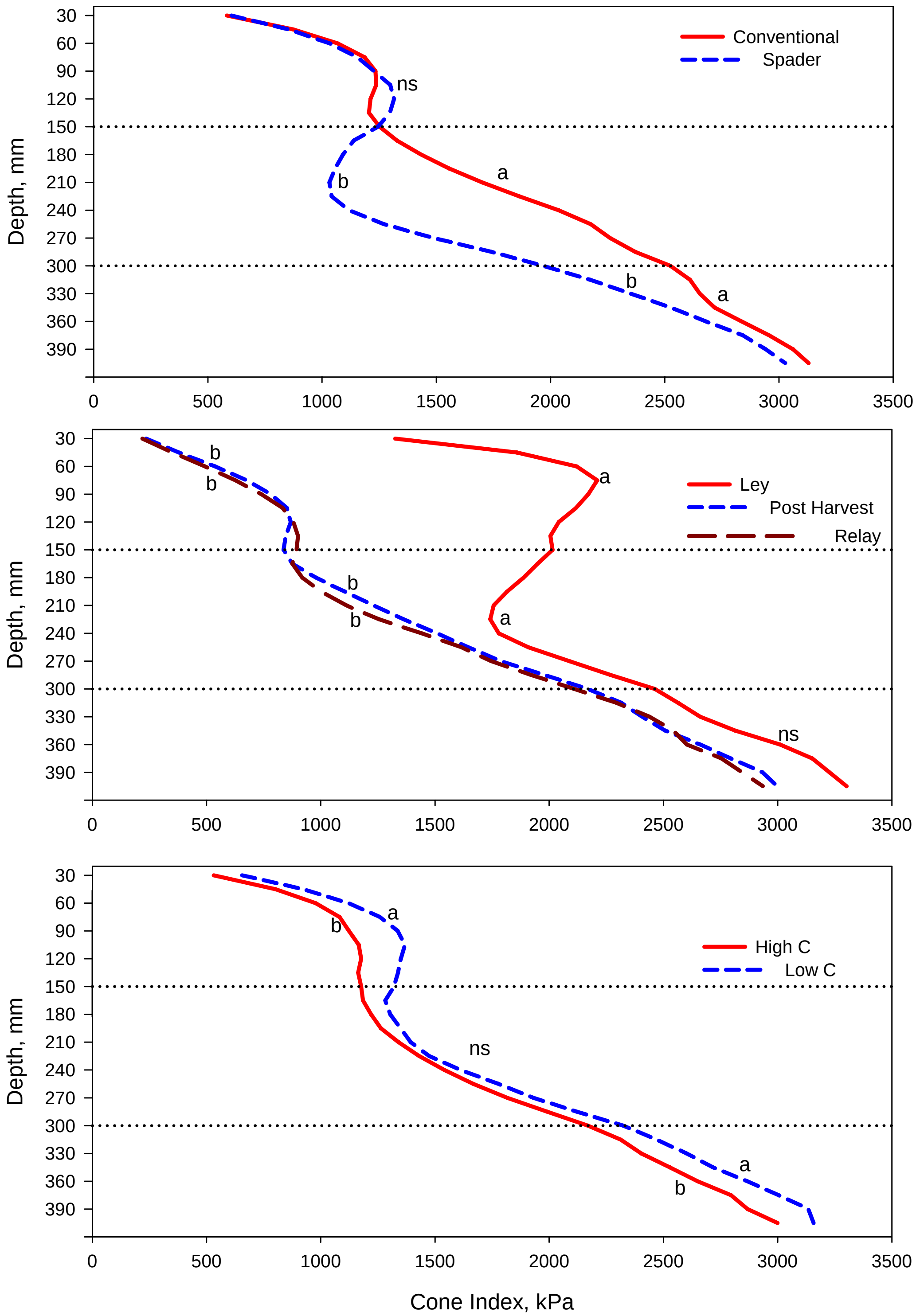

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Table 3. Infiltration rate, organic systems experiment, 2005-2007.

	2005		2006		2007	
	5 Jun	13 Jul	25 May	6 Jul	31 May	2 Jul
	------------------- mm/min ------------------					
Cover crop						
Ley	12	6	**2b**	**2b**	7	6
Fall	13	9	**13a**	**8a**	8	6
Relay	12	8	**9a**	**7a**	8	6
Amendment						
Low C	**11b**	7	**7b**	5	**7b**	**5b**
High C	**14a**	8	**10a**	6	**8a**	**7a**
Interaction						
CC x amendment	NS	NS	NS	*	NS	***

[1]Means within a column and treatment group followed by different letters are significantly different at P<0.05 by protected LSD.

Table 4. Mean values for amendment effects on dehydrogenase activity, b-glucosidase activity and particulate organic matter (POM) carbon, 2004-2007.

	2004	2005		2006		2007
	August	May	July	May	June	May
Dehydrogenase (ug TPF/g soil/h)						
Low C	**1.40 b**	2.36	**1.87 b**	3.59	**2.68 b**	**3.12 b**
High C	**1.60 a**	2.52	**2.17 a**	3.81	**3.02 a**	**3.39 a**
B-Glucosidase (ug PNG/g soil/h)						
Low C	121	95	76	146	196	**131 b**
High C	124	94	75	146	191	**137 a**
POM C (g/kg soil)						
Low C	**3.49 b**	**4.49 b**	**5.17 b**	**10.3 b**	**11.8 b**	
High C	**4.52 a**	**6.60 a**	**7.58 a**	**16.0 a**	**17.8 a**	

[1]Means within a column and analysis followed by different letters are significantly different at P<0.05 by protected LSD.

Table 5. Mean values for tillage type effects on dehydrogenase and b-glucosidase activities 2004-2007.

	2004	2005		2006		2007
	Aug	May	July	May	June	May
Dehydrogenase (ug TPF/g soil/h)						
Conv	1.50	**2.28b**	2.03	**3.87a**	**3.02a**	**3.11b**
Spader	1.48	**2.61a**	2.02	**3.53b**	**2.68b**	**3.40a**
B-Glucosidase (ug PNG/g soil/h)						
Conv	125	91	**71b**	152	197	**129b**
Spader	119	98	**79a**	140	189	**139a**

[1]Means within a column and analysis followed by different letters are significantly different at P<0.05 by protected LSD.

Dehydrogenase and b-glucosidas. Dehydrogenase activity was greater in plots treated with the high C amendment compared with the low C amendment. Differences were significant on four of six dates analyzed between 2004 and 2007 (Table 4). Amendment affected b-glucosidase activity on only one date. Dehydrogenase activity was also affected by tillage. In May 2005 and 2007 activity was lower under conventional tillage, while in 2006 activity was greater under conventional tillage (Table 5). The conventional plots were plowed (moldboard plow) in the spring of 2005 and 2007, suggesting plowing could temporarily reduce dehydrogenase activity. The plots were not plowed in 2006. Additional data will be needed to see if this trend continues. B-glucosidase activity was greater under spader tillage on two of the six dates, with no clear trends emerging.

Nematodes and collembola. Nematode community analyses completed thus far have indicated a significant and consistent effect due to amendment, no significant effect due to tillage, and major changes to the nematode community due to cover crop rotation only during the pasture phase of the ley treatment.

Nematode populations were higher with the low-C broiler litter amendment than with the high-C on-farm compost at mid-summer in 2005, 2006, and 2007. Community analyses for 2005 and 2007 (2006 not completed yet) indicated greater bacterial-feeding nematodes with broiler litter at both of these samplings, but no differences in fungal-feeding, omnivorous/predacious, or plant pathogenic nematodes (Figs. 5 and 6). While the on-farm compost supported less bacterial-feeding nematodes, the community structure was not shifted significantly toward fungal-feeding nematodes or a fungal-based food chain as evidenced by the lack of difference in the channel index (CI).

Figure 5.

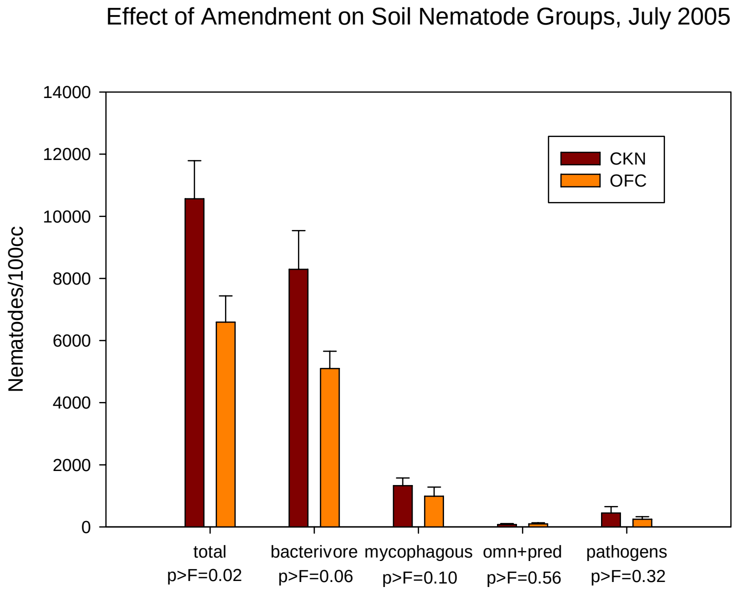
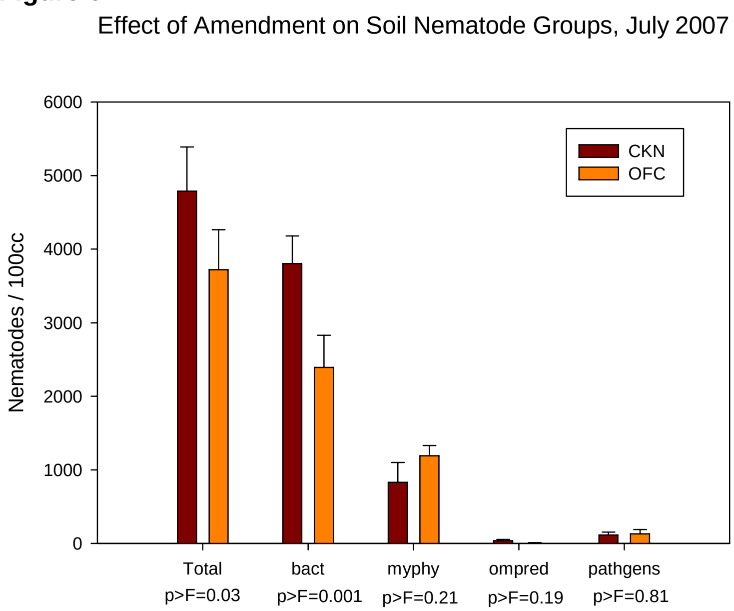


Figure 6..



Community analysis of nematode samples taken mid-summer 2006, when the ley treatment was in pasture, is still underway. However, community analysis has been completed for a sampling done April 2007, before spring tillage. Therefore, this sampling reflects the rotations in place in 2006. At the time of this sampling, the ley had not been tilled for 18 months, the relay treatment for 9 months, and the post-harvest treatment for about 6 months. All of the treatments indicated a greater proportion of fungal-feeding nematodes (greater CI value) than during the summer 2005 and 2007 samplings (Table 6). Furthermore, the difference between the ley treatment and the other two treatments was highly significant, indicating that the pasture phase promoted much more fungal activity and more of a fungal-based food web. The ley had a higher maturity index (MI) than the post-harvest treatment, indicating a more stable ecosystem. Conversely, the post-harvest treatment trended toward a higher enrichment index (EI) ($P<0.09$) than the ley and relay treatments. A higher EI indicates more dominance in the population of early colonizing bacterial- and fungal-feeding nematodes, and this enrichment in the post-harvest treatment was likely due to the relatively recent tillage and incorporation of organic matter during the previous fall.

Collembola numbers were most strongly affected by tillage frequency and unaffected by tillage type, while amendment had a variable effect. In the late fall of 2005 and 2006 the relay cover crop treatment had greater collembola numbers than the post-harvest cover crop treatment, reflecting the more recent tillage that occurred in the post-harvest cover treatment prior to planting cover crops. During 2006, when the ley treatment was in the pasture phase and undisturbed by tillage, it had much greater collembola numbers than the other treatments (Fig. 7). Collembola population in the pasture in 2006 was similar to that in the adjacent grass alleys, which have been untilled since 2003.

Soil pH, exchangeable K, and organic matter (0-30 cm depth) were higher with the High C amendment (on-farm compost) compared with the Low C amendment (broiler litter) (Table 7). Exchangeable K levels showed increasing trends for both amendment treatments over time. Bray-P levels are not shown, because they were very high (> 100 mg/kg) at the start of the experiment, due to historical (pre-1990) applications of P fertilizer and chicken manure. The ley treatment, which received biennial rather than annual amendment applications, had slightly but significantly higher pH in 2005 and 2006, and significantly lower exchangeable K in 2006. Significant cover crop x amendment interactions in 2005 and 2006 were the result of smaller amendment effects in the ley treatment, an expected result of less frequent amendment applications.

Table 6. Effect of Rotation on Nematode Community Indices.

Rotation	EI Mean	EI SE	SI Mean	SI SE	CI Mean		CI SE	MI Mean		MI SE
July 2007										
Ley	87.3	2.31	30.0	10.48	5.1		1.86	1.50		0.09
Relay	90.6	1.55	24.4	3.46	3.4		0.31	1.37		0.04
PH	92.0	1.01	41.2	7.74	2.9		1.38	1.40		0.07
	p>F =0.30		*p>F =0.41*		*p>F =0.60*			*p>F =0.45*		
April 2007										
Ley	71.5	3.3	50.3	4.0	20.8	a	3.6	2.0	a	0.03
Relay	78.5	4.5	34.8	5.3	7.3	b	2.0	1.7	ab	0.1
PH	87.3	4.0	39.8	5.0	6	b	2.4	1.5	b	0.1
	p>F =0.089		*p>F =0.162*		*p>F =0.008*			*p>F =0.037*		
July 2005										
Ley	92.6	2.2	48.5	8.8	1.3		0.6	1.6		0.2
Relay	89.0	1.3	50.8	8.5	2.4		0.7	1.8		0.1
PH	90.8	2.9	56.6	7.7	2.3		0.4	1.6		0.1
	p>F =0.43		*p>F =0.52*		*p>F =0.12*			*p>F =0.18*		

Figure 7. Effect of cover crop treatment on collembola populations, 2005 and 2006. Ley treatment was in the pasture phase in 2006.

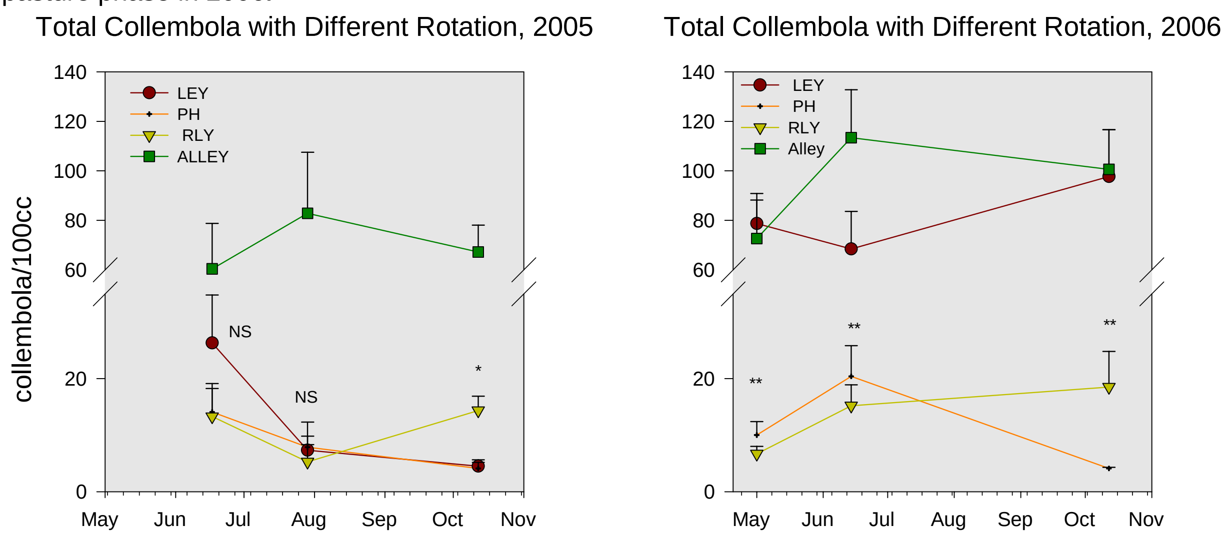


Table 7. pH, exchangeable K, and soil organic matter, organic systems experiment 2004-2006.

	2004 pH	2004 Exch. K	2005 pH	2005 Exch. K mg/kg	2005 OM g/kg	2006 pH	2006 Exch. K mg/kg	2006 OM g/kg
Ley	6.0	204	**6.2 a**	260	37	**6.2 a**	**229 b**	38
Fall	6.0	201	**6.0 b**	270	40	**5.9 b**	**370 a**	41
Relay	5.9	240	**6.0 b**	273	40	**6.0 b**	**375 a**	42
Low C	**5.9 b**	**180 b**	**5.9 b**	**212 b**	**36 b**	**5.8 b**	**247 b**	**37 b**
High C	**6.0 a**	**250 a**	**6.3 a**	**323 a**	**42 a**	**6.3 a**	**402 a**	**44 a**
CC x amendment	NS	NS	**	**	**	***	***	**

[1]Means within a column and treatment group followed by different letters are significantly different at P<0.05 by protected LSD.

Initial (2002) field average soil test values were: pH 5.65; K 120 mg/kg; OM 32 g/kg

Crop yield. Treatments affected crop yields in a few instances during 2003-2006 (Table 8). Amendment effects on snap bean in 2003 and broccoli in 2006 appeared to be related to the amount and timing of available N. Amendment and cover crop differences in spinach in 2004 were related to seedbed condition, resulting in differences in spinach stand.

Table 8. Yield of cash crop. Only statistically significant (0.05) differences are shown.

Year	Crop	Yield (fresh ton/acre) Overall Mean	Amendment High C compost	Amendment Low C broiler litter	Cover Crop Post-harvest	Cover Crop Relay	Cover Crop Ley[1]	Tillage Spader	Tillage Conv.
2003	Snap bean	7.7	8.3	7.0					
2004	Spinach	4.8	4.0	5.6	5.5	4.1			
2005	Acorn Squash	18.8							
2005	Delicata Squash	13.0							
2006	Snap bean	6.8							
2006	Broccoli	5.0	4.6	5.5					
2006	Spinach	3.2							
2006	Acorn squash	27.4							
2007	Snap bean	4.8			6.0a	4.4b	4.2b		
2007	Broccoli	4.5			5.4a	4.5b	3.7c	4.7	4.3
2007	Spinach	8.7			11.8a	9.2b	5.0c	9.3	8.0
2007	Delicata squash	16.5						17.3	15.7

[1] Ley treatment did not have cash crops in 2004 and 2006

Table 9. Post-harvest soil nitrate-N, 0 to 30-cm depth, 2004-2006.

	2004	2005	2006
	mg NO_3^- N/g soil		
Amendment			
Low C	16	6	**21 a**
High C	17	6	**10 b**
Cover Crop			
Ley	**4 b**	6	**2 b**
Fall	**23 a**	6	**26 a**
Relay	**22 a**	6	**19 a**
Tillage			
Conv	16	7	**13 b**
Spader	16	6	**18 a**
CC x amendment	NS	NS	***

[1]Means within a column and treatment group followed by different letters are significantly different at P<0.05 by protected LSD.

In 2007 both cover crop treatment and tillage had significant effects on crop yield. Snap bean, broccoli, and spinach following the post-harvest cover crop all had greater yields than following either the relay cover crop or pasture. Moderate to poor stands of the relay vetch would have reduced N contribution from the cover crop compared with the more vigorous stands of the post-harvest rye-vetch blend. The ley treatment received no amendments and relied solely on N from the plowed down pasture. Interpretation of yield responses in terms of soil available N status in the cover crop treatments will be done when 2007 N analyses are complete. Spader tillage increased yields of broccoli, spinach, and squash compared with conventional tillage. The reason for the yield benefit from spader tillage is not yet apparent. We have observed few measurable differences in physical and biological soil quality between the spader and conventional tillage treatments, with the exception of soil compaction in the subsurface. Differences reflected in the yields may be evolving as each system matures.

Post-harvest soil nitrate showed different trends each year from 2004 through 2006 (Table 9). In 2004 nitrate-N was much greater in the post-harvest and relay cover crop treatments than the ley treatment, a reflection of management during that year. The ley treatment was in the pasture phase during 2004, receiving no amendments and having an efficient root system scavenging nitrogen, resulting in a very low residual. The higher nitrate levels in the other treatments indicate some unutilized available N at the end of the crop season. The amendment treatments had similar residual nitrate levels, indicating similar levels of N availability to the crops. In 2005, when all treatments were planted to the cash crop, all post-harvest nitrate levels were low, indicating nearly complete use of available N by the cash crop. Squash yields in 2005 were lower than those observed in 2006 and 2007, and the plots may have had sub-optimal levels of available N. However, in-season levels of nitrate-N (see below) appeared adequate for agronomic yields. The ley treatment was back in the pasture phase in 2006, and had very low residual nitrate-N levels as expected. Nitrate levels following application of broiler litter (low C) were greater than those following application of on-farm compost (high C), indicating application of the broiler litter at levels greater than crop need. Nitrate levels were also higher following spader tillage than conventional, although the reason for this difference is not clear.

Table 10. In-season soil nitrate-N, 0 to 30-cm depth, 2005-2006.

	2005 23 May	2005 21 June	2006 3 May
	mg NO_3^- N/g soil		
Amendment			
Low C	**21 a**	**43 a**	**21 a**
High C	**16 b**	**37 b**	**14 b**
Cover Crop			
Ley	**14 b**	36	**1 b**
Fall	**18 ab**	39	**28 a**
Relay	**22 a**	46	**25 a**
Tillage			
Conv	17	39	18
Spader	20	42	18
CC x amendment	NS	NS	*

[1]Means within a column and treatment group followed by different letters are significantly different at P<0.05 by protected LSD.

In-season soil nitrate-N was measured several weeks after amendment application in 2005 and 2006 and mid-season in 2005. Results showed significant available N for all treatments in 2005 and all treatments except the pasture in 2006 (Table 10). The low C broiler litter supplied more early season N than the compost, as expected. The ley provided the least early season N in 2005, but mid season N levels indicated adequate levels for all treatments. The low level in the pasture in 2006 was a result of no amendment application, and efficient use of available N during the pasture phase. Data for 2007 have not been analyzed.

Conclusions. Amendment had the greatest effect on soil properties. The High C amendment (on-farm compost) decreased bulk density and increased POM C, total OM, dehydrogenase activity, soil pH, and exchangeable K compared with the low C amendment (broiler litter). All of these effects were measured each year, and were the result of an immediate response to incorporation of the compost. The High C amendment also increased infiltration rate, with a transient increase observed in 2005 and 2006 and a more lasting increase in 2007. Amendment did not affect compaction until 2006, when a significant decrease in compaction in the surface 15 cm was observed with the High C amendment. Amendment has not affected aggregate stability, while effects on b-glucosidase activity and collembola are not yet clear. Total and bacterial-feeding nematodes were increased by the low C amendment (broiler litter), probably as a response to N rather than C. Crop yield also showed occasional responses to amendment, which usually appeared to be related to N. The amendment effects were greater in the relay and post-harvest cover crop treatments, which received amendments every year, compared with the ley treatment, which received amendments only in 2003 and 2005..

Cover crop effects were often related to the frequency and timing of tillage in each cover crop rotation. The post-harvest cover crop treatment was fully tilled every spring and fall, while the relay treatment was tilled in the spring only (except for 2004), and the ley was tilled spring and fall every other year. During the pasture phase, the ley treatment had higher bulk density, greater compaction in the surface soil, slower infiltration, and fewer nematodes, but greater nematode diversity and greater numbers of collembola. Collembola responded negatively to tillage, but numbers rebounded within months when the soil was not disturbed. In 2007 yields were affected by the previous cover crop, a likely result of soil nitrogen status.

The type of tillage affected soil compaction, with consistent differences between spader and conventional tillage in the 15-30 cm depth occurring every year. Plots tilled with the spader also showed occasional, transient differences in other soil properties, and in 2007 showed improved crop yields.

On-farm soil quality evaluations

Mean bulk density, infiltration, aggregate stability, and soil test values are compared across on-farm sites in Tables 11-13. Nutrient analyses for 2006 were similar to 2005, and only 2005 data are shown.

Soil test values showed a wide range in organic matter, reflecting native soil properties, current and past management, and length of time in organic production. P and K levels also varied widely, with four locations

Table 11. Mean and range soil test pH, exchangeable K, and Bray P at on-farm sites, 2005.

Farm	pH Mean	pH Range	Exec. K Mean mg/kg	Exec. K Range mg/kg	Bray-P Mean mg/kg	Bray-P Range mg/kg
C	6.3	5.5 - 6.6	225	97 - 321	39	26 - 49
F	5.8	5.5 - 5.9	227	96 - 402	21	13 - 31
KA	6.2	6.0 - 6.4	175	165 - 185	128	119 - 137
KH	6.4	6.2 - 6.5	235	124 - 318	445	245 - 559
M	6.2	5.8 - 6.8	388	273 - 465	304	233 - 384
ND	6.1	6.0 - 6.2	194	150 - 243	18	14 - 26
NP	7.9	7.8 - 8.1	62	48 - 81	25	9 - 54
T	6.2	6.0 - 6.4	453	280 - 606	485	418 - 547

having excessive levels of P. Post-harvest nitrate levels were measured at only three farms in 2005 and four farms in 2006, but all suggest conservative N management, with low levels of nitrate-N available for leaching at the end of the growing season. The farm with the lowest soil N levels showed visible signs of N deficiency in the crops. Infiltration rates reflected soil texture and to a lesser extent management. Infiltration data for 2005 (not shown) and 2006 were similar. Penetration resistance had different patterns among farms, but was generally within the range of that observed in the systems experiment. (Fig 8).

Table 12. Mean and range soil organic matter (LOI) and post-harvest soil nitrate-N (0-30 cm depth) at on-farm sites, 2005

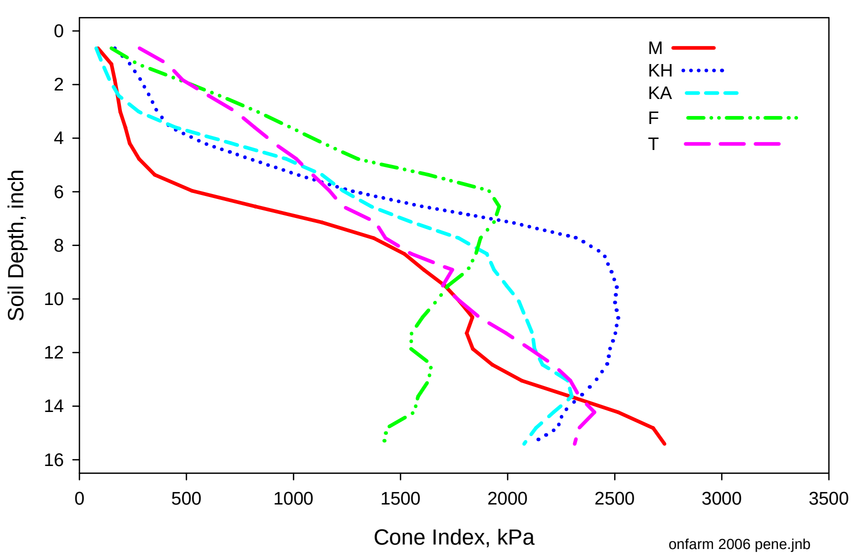
Farm	OM, LOI Mean %	OM, LOI Range %	Nitrate Mean mg/kg	Nitrate Range mg/kg
C	5.5	4.4 - 6.5	.	.
F	7.0	4.7 - 8.4	.	.
KA	6.7	6.3 - 7.0	8	6 - 10
KH	5.1	4.7 - 5.4	11	4 - 20
M	2.7	2.4 - 3.1	4	2 - 8
ND	4.3	3.8 - 4.6	.	.
NP	2.7	2.2 - 3.1	.	.
T	2.9	2.6 - 3.4	.	.

Table 13. Bulk density, infiltration rate, and aggregate stability at on-farm sites, 2005 and 2006.

Farm	Number of Sampling Locations	2005-06 Average Bulk Density[1], g/mL	2006 Infiltration[2] rate, mm/min H_2O	2005 Proportion of stable aggregates >0.53 mm
C	4	1.05	21.7	0.68
F	4	1.08	5.5	0.80
KA	2	1.02	3.8	0.40
KH	4	1.02	9.5	0.33
M	6	1.04	11.8	0.56
ND	3	1.28	.	0.75
NP	3	1.40	.	0.78
T	3	1.09	7.5	0.62

[1] Mean bulk density across all sampling locations at each farm site. Three replicate measurements were taken within each sampling location. Mean over all sampling locations and two years (except 2005 only at ND and NP).
[2] Mean infiltration rate across all sampling locations. Five replicate measurements were taken within each sampling location

Figure 8. Mean penetrometer resistance averaged over field location at each on-farm collaborator site sampled in 2006.



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