



Effects of organic transition strategies for peri-urban vegetable production on soil properties, nematode community, and tomato yield

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ABSTRACT

Four organic transition strategies including tilled fallow (FA), mixed-species hay (HA), low intensity open-field vegetable production (FV) and intensive vegetable production under high tunnels (HT), each with and without annual compost amendment, were analyzed for nematode communities and soil properties from 2003 to 2006. Tomato was grown in all plots at the end of the transition period (2006). Overall the enrichment opportunist bacterivore nematodes belonging to c-p 1 (colonizer-persister) and general opportunist c-p 2 classes were favored by compost amendment. Hay (HA) had the highest abundance of c-p 1 bacterivores followed by HT with compost compared to other compost treatments. HA and HT without compost showed similar levels of c-p 2 but lower c-p 1 bacterivores compared to their compost-amended counterparts. Nematode food webs in all strategies with and without compost had low structure (SI) and enrichment index (EI) values. The lack of increase in EI in compost-amended plots was mainly due to the higher abundance of c-p 2 bacterivores compared to c-p 1 bacterivores. A decline of SI in HA plots after the incorporation of hay and consistently low SI in HT where soil disturbance was more frequent and temperature profiles were significantly different from those in open-field settings demonstrate that compost amendment alone is insufficient to increase trophic linkages in the soil food web. Although compost application increased the organic matter, microbial biomass (MB) and N levels compared with non-amended controls in general, N and MB were the highest in HT and HA. In temperate climates, soil temperatures in high tunnels covered year-round tend to exceed those in open fields in spring and fall months. The soil food web, in turn, may remain more active in these settings contributing to enhanced N mineralization. In this study, tomato yield in HT plots exceeded yield in other treatments potentially due to the season extension and higher N availability.

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1. Introduction

Competition for land, anti-farming sentiment, weakening farming infrastructure, and low commodity prices limit urban and peri-urban agriculture. Organic production is a partial solution to these challenges for many urban/peri-urban farmers (Lamont et al., 2002; Tu et al., 2006). Premium prices based on the “certified organic” designation are usually available only after 3 years have elapsed since the recent use of restricted materials or practices, as per the United States National Organic Standards Act (NOS). The

3-year transition period is usually difficult since mineral nutrient availability and crop yields are unstable, premium prices unavailable, and pests (insects, parasitic nematodes, pathogens and weeds) potentially severe (Clark et al., 1999; Tu et al., 2006). Farmers appear to select transition strategies based mainly on economic (including production potential), labor and other considerations but reports outlining agroecological consequences of these strategies can also be persuasive (Clark et al., 1998).

In organic systems, nitrogen and other essential plant nutrients are typically derived to the greatest extent from organic matter decomposition (Drinkwater et al., 1995; Laakso et al., 2000). The addition of organic matter to soil increases microbial activity and enlarges the food base for microbial grazers like free-living nematodes (Alon and Steinberger, 1999; Bongers and Ferris, 1999; Ferris et al., 1999; McSorley and Frederick, 1999; Papatheodorou et al., 2004). Nematodes are abundant and diverse invertebrates (Yeates, 1979) that are sensitive to changes in the soil environment caused by different agroecosystem management practices

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(Sohlenius and Wasilewska, 1984; Yardim and Edwards, 1998; Neher and Olson, 1999; Yeates et al., 1999; Forge and Simard, 2001; Briar et al., 2007a). Nematodes can be grouped into five major trophic groups; bacterivores, fungivores, plant parasites, predators and omnivores (Yeates et al., 1993). Plant-parasitic nematodes are primary consumers, while bacterivores and fungivores graze on decomposer microbes and contribute to nutrient mineralization (Ingham et al., 1985; Ferris et al., 1996; Ferris et al., 2004). Predatory nematodes regulate the soil food web by preying on nematodes and other invertebrates in the soil (Grewal et al., 2005). Nematode faunal analysis based on the relative weighted abundance of colonizer–persister (c–p) classes (*r* versus *K* life strategists) provides a quantitative measure of the nematode community structure and the probable condition of the soil food web (Ferris et al., 2001). The analysis comprises food web indices including enrichment, structure, basal and channel, which provide critical information about soil processes in different ecosystems (Ferris et al., 2001; Bulluck et al., 2002; Briar et al., 2007b).

We set out to document the agroecological consequences of four major organic transition strategies with potentially specific application in peri-urban areas. The strategies varied in management intensity (including soil disturbance), crop species diversity and anticipated biomass and economic production potential. Replicated main plots of each strategy contained subplots that were amended with dairy manure compost or not amended. We hypothesized that the unique characteristics of each strategy and compost incorporation would result in measurable differences in biomass production and soil physical, chemical and biological properties.

Although assessment of nematode trophic groups provides insights into the soil environment, c–p classes within the same trophic group, especially bacterivores, may have differential responses to crop management strategies (Ferris and Matute, 2003; Ferris et al., 2004). Therefore, the various transitioning strategies were assessed using nematode trophic groups and dominant c–p classes as bioindicators. In addition nematode faunal indices proposed by Ferris et al. (2001) were calculated for the likely assessment of the condition of the soil food webs. Our previous research has shown that conventional farming systems dependent upon synthetic inputs show large shifts in nutrient pools upon switching over to organic inputs (Briar et al., 2007a). We further explored the association of nematodes with soil properties after the addition of organic matter and establishment of transition strategies.

2. Materials and methods

2.1. Field plot design and organic transition strategies

A replicated split-plot field experiment was conducted in 2003–2006 at the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio (40°47'N, 81°55'W; 310 m elevation). The soil at the site was a moderately well drained Wooster silt loam initially with approximately 2.2% organic matter, 40 mg kg⁻¹ P, and 95 kg⁻¹ K (Benítez et al., 2007). The study site had been employed in horticultural research involving conventionally grown vegetable and grain crops for many years prior to 2003. Four, 39.6 m wide × 41.3 m long replicates containing four main-plot transition strategies arranged in a randomized complete block design were established in 2003. Each main plot measured 18.29 m wide × 17.07 m long and was subdivided into equal-size subplots receiving dairy manure compost or no compost. Transition strategy main plots were managed as separate systems from 2003 to 2005 but were cropped to tomato in 2006.

The four organic transition strategies were tilled fallow (FA), a single planting of mixed species perennial hay (HA), low intensity open field vegetables (FV) and intensive vegetable production

under high tunnels (HT). In FA plots, weed seedlings were removed with machine cultivation several times during spring to fall each year and a cover crop (rye or wheat) was planted each fall, killed by mowing the following spring and incorporated. HA plots consisted of a combination of eight hay species (*Festulolium* or rye fescue) under-sown with alfalfa, red and white clover, timothy, chicory, orchard-grass and plantain in equal proportions. Two or three cuttings were taken each year from the HA plots using standard techniques with remaining biomass incorporated into the soil only in Spring 2006 in preparation for tomato transplanting. High tunnels were constructed as plastic enclosed structures (Lamont et al., 2002) measuring 6.4 m × 14.6 m which provide partial control over environmental variables, chiefly temperature, moisture as rain or snow, and solar radiation. As a result, vegetable cropping is possible in high tunnels over a wider portion of the calendar year compared to open field settings. The intensive vegetable production under high tunnels (HT) consisted of potato-mixed vegetables (lettuce, spinach, Swiss chard, radish, and beet) in 2003, mixed vegetables-zucchini squash-mixed vegetables in 2004 and mixed vegetables-green bean-mixed vegetables in 2005. FV consisted of potato-mixed vegetables in 2003, butternut squash-wheat in 2004, and green bean-lettuce-wheat in 2005.

Split-plots within each main plot strategy were established to test dairy manure compost incorporation effects on major soil and plant variables. One half of each main plot received no compost whereas the other half received application of composted 60% separated dairy solids, 30% sawdust bedded manure, and 10% straw bedded manure at rates (16.87 Mg/ha) calculated to supply a portion of the anticipated crop N requirement for each treatment crop. Compost was applied by a standard manure spreader or by hand uniformly over the subplot area and incorporated by chisel plowing and discing or rototilling within 48 hr of surface deposition to FA, FV or HT subplots or allowed to remain in place after deposition to HA subplots. Application of compost was made to the FA, FV, and HA subplots once a year and while two applications were made to the HT each year since 2003. In spring of 2006 compost was applied at 99.73 kg of N/ha in the HA, FV, FA plots and 89.69 kg of N/ha in the HT. There was 55.85 Mg/ha of compost applied to HA, FV, and FA and 10.40 Mg/ha in each HT subplot. The difference in application rates was due to the N credits that were applied from previous years.

FV and HT vegetable crops were rainfed or drip- and hand-irrigated as needed. Drip tape (510-12-450 TSX; 1.70 L/min/40.48 m) was used in all 4 years. Drip irrigation was applied April–November in FV and HT plots while HT crops were hand-irrigated November–March. Irrigation was scheduled 2003–2006 based on the hand-feel method, forecast and crop status. In 2006, tomato plots were irrigated every 2–3 days after crop establishment through to completion of fruiting, approximately 1–3 cm per week, adjusted for rainfall.

2.2. Tomato plot establishment and yield

Tomato seedlings were set by hand on April 14 (HT) and June 15–16 (all open field plots) into standard raised beds mulched with straw (HT) or covered with standard black agricultural film at shaping (all open field plots). Plants and plots were maintained using methods consistent with regional, certifiable-organic commercial and research practice. These tactics included removal of mature leaves at nodes 1–3 above the soil line, trellising using the 'Florida Weave' system, maintenance of consistent soil moisture levels, weed removal through mechanical cultivation and application of labeled curative or preventative pesticides.

Subplots contained six (all open field plots) or two (HT) rows of tomato ('Mountain Spring', 'Florida 47') seedlings placed at in- and between-row spacings of either 0.45 m × 1.22 m (HT) or

0.61 m × 1.52 m (all open field plots), respectively. Both tomato varieties were included in all main and subplots, constituted sub-subplots.

Tomato fruit at “blush” Stage 5 of maturity were collected weekly from the center of each sub-subplot, counted, weighed, sorted into marketable and non-marketable categories and re-counted and re-weighed. Fruit were collected from areas measuring 6 m × 2.3 m × 2.4 m (2.3 m × 2 rows) in open field and HT subplots, respectively.

2.3. Soil sampling

Six soil cores (5 cm diameter and 15 cm deep) were removed randomly from the central portion of each sub-plot and combined to form a composite soil sample per sub-plot. Soil samples were collected for analysis of nematodes and soil properties once per year in the month of March from 2003 to 2005 while the last sampling was done in October of 2006 at the time of tomato harvest. Large plant parts or stones were removed from the samples by passing them through a soil sieve (6 mm mesh). All soil samples were stored in the dark overnight at 5 °C.

2.4. Nematode extraction, identification and counting

Nematodes were extracted from a 10 g subsample taken from each composite soil sample using the Baermann funnel technique (Flegg and Hooper, 1970). Nematodes were collected after 72 h, heat killed, and fixed with triethanolamine formaldehyde (TAF) solution (Shepherd, 1970). Specimens were viewed using an inverted microscope at 40× magnification and identified to genus/family level using diagnostic keys by Goodey (1963), Siddiqi (1986), Bongers (1994), Jairajpuri and Ahmad (1992). All identified nematode genera were assigned to a trophic group (plant-parasitic, fungal feeder, bacterial feeder, omnivore, or predator) according to Yeates et al. (1993). Nematode genera were assigned a colonizer–persister value (c–p value) according to Bongers (1990). Nematode counts were not corrected for extraction efficiency.

2.5. Soil properties analysis

Soil bulk density (BD), total organic matter (TOM), mineral associated organic matter (MAOM) (<0.05 mm), particulate organic matter (POM) (0.05–2 mm), mineral-N (NH₄⁺-N and NO₃⁻-N), and dissolved organic-N (DON), were analyzed using standard methods (Sims et al., 1995) and microbial biomass-N (MB-N) using a modified chloroform fumigation method (Brookes et al., 1985) at the Field Crop Ecology Laboratory, OARDC, Wooster, OH.

2.6. Soil temperature

Soil temperature at 10 cm depth was recorded using a thermometer installed inside high tunnels and connected to a data logger. Outside field soil temperature data were obtained from the Ohio Agricultural Research and Development Center Weather Station located 0.8 km away from the experimental site.

2.7. Data analyses

The enrichment (EI) and structure (SI) indices were calculated according to Ferris et al. (2001), with basal components (*b*) of the food web (fungal and bacterial feeders in the c–p 2 group) calculated as $b = \sum k_b n_b$ where k_b is the weighted constant for the group, and n is the number of nematodes in that group. Enrichment (*e*) and structure (*s*) components were similarly calculated, using nematode groups indicative of enrichment (bacterivores of c–p 1,

and fungivores of c–p 2), and groups supporting structure (bacterivores of c–p 3–5, fungivores of c–p 3–5, omnivores of c–p 3–5, and predatory nematodes of c–p 2–5). Finally, the EI was calculated as $100 \times e/(e + b)$, and the SI as $100 \times s/(s + b)$.

Soil properties and nematode descriptors (c–p and trophic groups) were compared between the main- and subplot treatments using repeated measures analysis of variance (ANOVA). Baseline data collected in 2003 before the establishment of treatments was not included in the analysis, but a simple mean of all plots is presented. All four transition strategies and the with–without compost application subplots were compared for nematode trophic and c–p groups, and soil properties using LSD pairwise mean comparison tests. Relationships between soil parameters and, nematode c–p or trophic groups was analyzed by performing Spearman's rank correlation analysis. Tomato yield data were collected only in 2006 and compared among the eight treatments using a pairwise means comparison test. To determine the relationship of tomato yield with soil properties or nematode c–p and trophic group, Spearman's rank correlation was performed only using the soil properties and nematode data recorded in 2006.

Nematode population data were transformed as $\ln(x + 1)$, total organic matter data as arcsin of the square root of *x* while MAOM, POM, NH₄⁺-N, NO₃⁻-N, and DON were transformed using square root transformations prior to statistical analyses to meet the ANOVA assumptions. No transformation was applied to soil bulk density data and nematode indices values. The probability level of $P \leq 0.05$ was regarded as significant. ANOVA and mean comparison tests were performed using SAS Version 9.00 (SAS, 2003) while correlation was done using Minitab Version 14 (Minitab, 2007).

3. Results

During the course of this study 27 nematode genera were identified from the experimental plots. In the bacterivore group, seven were identified in c–p 1 class (*Rhabditis*, *Mesorhabditis*, *Rhabdolaimus*, *Panagrolaimus*, *Diplogasteroides*, *Teratocephalus* and *Monhystera*), four in c–p 2 (*Cephalobus*, *Acrobeloides*, *Acrobeles*, *Plectus*) and one in c–p 4 (*Alaimus*). Two fungivore genera (*Aphelenchoides* and *Aphelenchus*) were in c–p 2 class. Only one predatory genus in c–p 4 class (*Mononchus*) and three omnivores in c–p 4 (*Dorylaimus*, *Eudorylaimus* and *Pungentus*) were observed. Three plant-parasitic genera were in c–p 2 class (*Tylenchus*, *Filenchus* and *Psilenchus*), five in c–p 3 (*Pratylenchus*, *Paratylenchus*, *Tylenchorhynchus*, *Helicotylenchus* and *Hoplolaimus*) and one in c–p 5 (*Xiphinema*).

3.1. Effect of treatments on soil nematode communities and soil properties

3.1.1. Soil nematode communities

Main plot transition strategies differed ($P \leq 0.05$) for the abundance of dominant c–p 1 and cp 2 bacterivores (Table 1). Total fungivores and plant-feeders differed among the main plot strategies while the sum of omnivore and predatory nematodes did not differ among them. Compost impacts were apparent from significantly higher densities of bacterivores in the treatments with than in those without compost. C–p 1, c–p 2 and total bacterivores were higher in compost amended than non-amended plots averaged over main plot transition strategies while c–p 4 were at similar levels (Table 1). However, the effect of compost was not significant ($P > 0.05$) on any of the other trophic groups. The interaction between main plot transitioning strategies and compost was not significant for any of the trophic or c–p groups. Population densities of bacterivores fluctuated significantly over time. Sig-

Table 1

Mean abundance of nematode trophic group and c–p (colonizer–persister) classes/10 g soil in 2003, prior to the establishment of the organic treatments, and in 2004–2006 during the implementation phase.

		Bacterivores				Fungivores	Omnivore + predatory	Plant-feeders
		C–p 1	C–p 2	C–p 4	Total	Total	Total	Total
2003		24.6 ^a	50.1	4.1	78.9	31.0	8.9	23.0
Strategy	Compost							
FA	–C	12.0 ^b d	15.6 c	0.4 a	28.0 e	8.6 de	2.2 b	4.8 d
FA	+C	22.1 bcd	25.7 bc	0.4 a	48.2 cde	8.2 e	2.4 b	6.7 cd
FV	–C	17.5 cd	21.0 bc	0.4 a	39.0 de	13.7 cd	3.4 ab	14.6 ab
FV	+C	28.5 abc	29.0 bc	0.4 a	58.0 bc	12.0 cde	2.8 ab	10.7 bc
HA	–C	19.3 bcd	38.5 bc	1.4 a	59.2 bc	14.7 bc	3.4 ab	21.7 a
HA	+C	68.5 a	43.5 b	0.6 a	112.6 ab	14.3 bcd	6.8 a	20.6 a
HT	–C	29.8 abc	73.5 a	1.0 a	104.4 ab	26.7 a	2.6 ab	23.3 a
HT	+C	38.8 ab	95.6 a	1.0 a	135.3 a	20.7 ab	2.2 b	18.3 b
Averages	–C	19.6	37.2	0.8	57.6	15.9	2.9	16.1
	+C	39.5	48.4	0.6	88.5	13.8	3.6	14.1
ANOVA factor (df)								
Strategy (3)		0.02 ^c	<0.001	ns	0.0002	0.005	ns	<0.001
Compost (1)		0.001	0.03	ns	0.003	ns	ns	ns
Compost × strategy (3)		ns	ns	ns	ns	ns	ns	ns
Time (2)		0.001	0.002	0.005	0.0003	ns	ns	ns
Time × strategy (6)		ns	0.0002	ns	0.001	ns	ns	ns

^a Mean values of all four main plot strategies.

^b Pairwise mean comparison between all eight treatments including fallow (FA), field vegetable (FV), hay (HA) and high tunnel (HT) without (–C) or with compost (+C) application and values shown are averaged over four replicates and three sampling times. Different letters indicate significant differences between the strategies.

^c Numbers are *P*-values from repeated measures analysis of variance (ANOVA); ns: not significant ($P > 0.05$).

nificant sampling time × main plot strategy interactions for c–p 2 bacterivores ($P = 0.0002$), suggests a non-uniform trend across strategies.

Pairwise comparisons among all eight treatments showed that bacterivore nematodes tended to be favored by compost amendment. However, the compost effect was most obvious for c–p 1 bacterivores (Table 1). Hay with compost had the highest abundance of c–p 1 bacterivores followed by HT with compost. Non-amended HA and HT plots showed similar levels of c–p 2 bacterivores to their compost-amended counterparts but had fewer c–p 1 bacterivores. Fungivores were favored more by HT than the open field while no differences were observed between treatments with and without compost. HA and HT favored plant-feeders more than other strategies. Abundances of omnivore and predatory nematodes declined over time in general in all the subplots compared to the base line data in 2003 but both HA treatments with and without compost maintained greater mean abundance of these nematodes until 2005 compared to other treatments. However, omnivore and predatory nematodes declined following cultivation in 2006 even in the HA plots (data not shown). This trend was also reflected by the decline in SI in 2006 (Fig. 1). Overall nematode faunal profiles revealed lowly structured and moderately to low enriched food webs with HT being least enriched and most poorly structured.

3.1.2. Soil properties

Main plot transition strategies differed for BD, POM, NH_4^+ -N, DON, and MB-N, while no differences were found for TOM, MAOM or nitrate nitrogen (Table 2). Compost application clearly affected soil properties ($P < 0.05$) except for NH_4^+ -N which was only marginally affected ($P = 0.055$) by the compost application. Treatments with compost (averaged over main plots) were significantly higher in different forms of organic matter, N and MB-N than without compost. Soil bulk density was higher in without compost than with compost treatments. The compost × strategy interaction was only significant for POM ($P = < 0.001$). All measured soil properties varied over time except for NH_4^+ -N. Compost-amended HT had the lowest mean value for BD, followed by FV with compost, relative to their non-amended counterparts. TOM, MAOM, NH_4^+ -N, DON and MB-N were favored the most by HT with compost. HA with com-

post had the highest mean level of POM while MB-N and MAOM were close to the level in HT with compost.

3.2. Tomato yield

Tomato yield was significantly higher ($P < 0.05$) in HT than in open-field plots regardless of compost treatment (Fig. 2). Tomato yield was also slightly but not significantly higher in the compost amended compared with non-amended plots.

3.3. Relationships among nematodes, soil properties and tomato yield

Bacterivore nematode abundance correlated negatively with BD but positively with different forms of organic matter, mineral-N (NO_3^- -N) and MB-N (Table 3). A similar trend was observed for fungivores but was significant only for MB-N and MAOM. Plant-feeders also correlated positively with MB-N. The sum of omnivore and predatory nematode abundance was not correlated with any measured soil property. Total abundance of nematodes dominated by bacterivores correlated positively with mineral-N (NO_3^- -N), MB-N, POM and MAOM and negatively with BD.

Soil properties that correlated positively with total yield of tomato were MB-N and MAOM (Table 3). Among the nematodes, total bacterivores, c–p 2 bacterivores, fungivores and plant-feeders were positively correlated with tomato yield.

3.4. Soil temperature

Monthly mean 10 cm deep soil temperature inside the high tunnels was higher by 2–5 °C from January to May while from July to September it was marginally lower than the outside soil temperature.

4. Discussion

We evaluated and compared nematode communities, soil properties and tomato plant productivity in four main-plot organic transition strategies subdivided into compost-amended and non-amended subplots. The high tunnel strategy (HT) was specifically

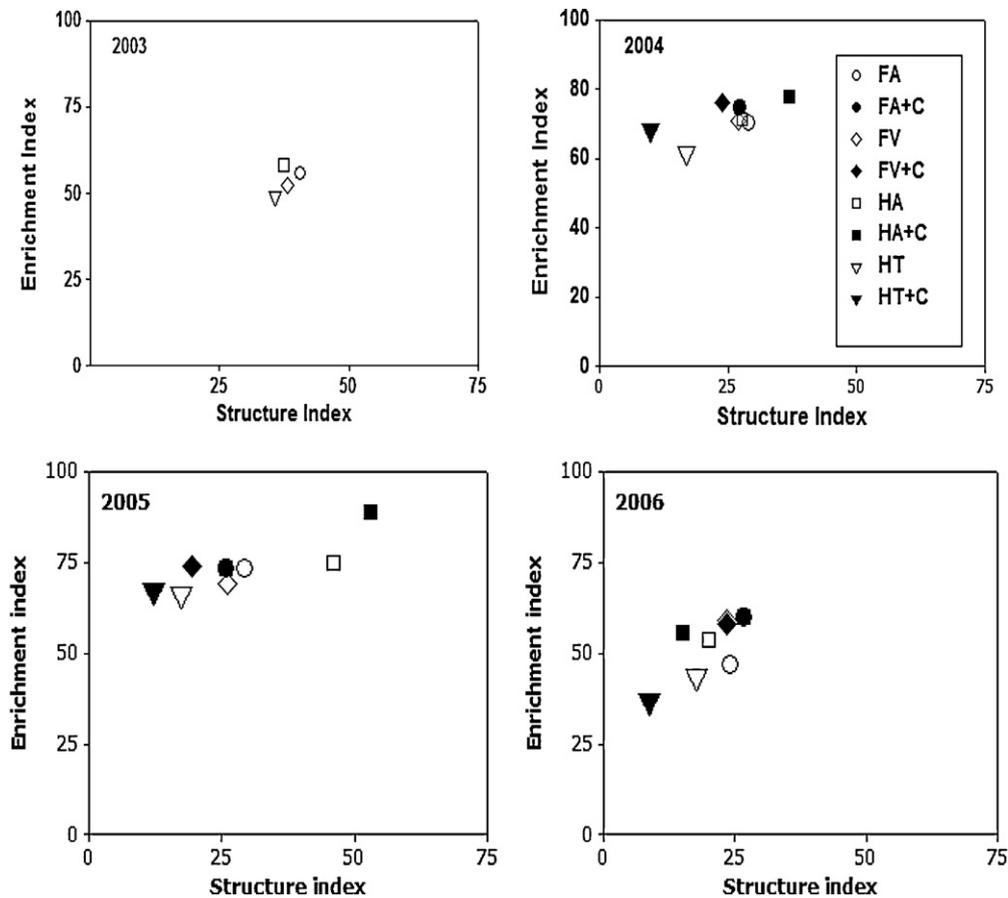


Fig. 1. Comparison and temporal progression of food webs indicated by nematode enrichment (EI) and structure (SI) indices in various organic transition strategies from 2003 to 2006. Soil sampling in 2003 was done before the compost application. Circles represent tilled fallow (FA), diamonds open-field vegetables (FV), squares mixed species hay (HA) and inverted triangles high tunnel (HT) strategy. Open symbols represent no compost application while filled symbols show compost application.

selected to attain partial control over environmental variables, allowing for vegetable crop production in early spring and late autumn, which is otherwise not feasible in open fields under northern Ohio climatic conditions.

Nematodes communities and soil properties responded to the addition of compost as observed in our previous research (Nahar et al., 2006; Briar et al., 2007a). The abundance of particular nematode c-p classes at a given point of time is largely affected by

Table 2

Mean values of soil properties in 2003, prior to the establishment of the organic treatments, and in 2004–2006 during the implementation phase.

		BD	TOM	POM	MAOM	NH ₄ ⁺ -N	NO ₃ ⁻ -N	DON	MB-N
2003		1.54 ^a	2.08	0.48	1.56	1.85	2.45	5.85	45.20
Strategy	Compost								
FA	-C	1.53 ^b ab	2.33 cd	0.32 c	1.70 bc	1.16 c	1.40 cd	4.58 d	17.29 d
FA	+C	1.48 bc	2.95 abc	1.27 b	2.11 abc	1.40 abc	2.57 bc	7.50 bcd	24.87 bc
FV	-C	1.56 a	2.34 cd	0.35 c	1.60 c	1.23 bc	2.38 bc	5.24 bcd	18.58 d
FV	+C	1.44 cd	3.16 a	1.34 ab	2.13 abc	1.46 ab	2.99 ab	8.34 b	28.43 abc
HA	-C	1.53 ab	2.29 d	0.45 c	1.91 abc	1.69 a	0.90 d	4.76 cd	25.40 abc
HA	+C	1.48 bc	3.05 ab	2.22 a	2.31 ab	1.59 a	3.28 a	7.65 bc	31.85 ab
HT	-C	1.46 c	2.41bcd	0.45 c	1.65 c	1.29 bc	1.89 bcd	6.24 bcd	23.15 cd
HT	+C	1.39 d	3.39 a	1.88 ab	2.33 a	1.61 a	4.65 a	12.90 a	32.35 a
Averages	-C	1.52	2.34	0.39	1.31	1.33	1.48	2.28	20.97
	+C	1.45	3.14	1.66	1.49	1.52	3.25	3.00	29.30
ANOVA factor (df)									
Strategy (3)		0.02	ns	<0.001	ns	0.048	ns	0.04	0.005
Compost (1)		<0.001	<0.001	<0.001	<0.001	0.055	0.002	<0.001	<0.001
Compost × strategy (3)		ns	ns	<0.001	0.06	ns	ns	ns	ns
Time (2)		0.004	0.001	<0.001	<0.001	ns	<0.001	<0.001	0.001
Time × strategy (6)		0.01	0.01	<0.001	0.005	0.002	ns	ns	ns

BD: soil bulk density, TOM: % total organic matter, POM: particulate organic matter (0.05–2 mm), MAOM: mineral associated organic matter (<0.05 mm), and mineral-N (NH₄⁺-N and NO₃⁻-N), DON: dissolved organic-N, and MB-N: microbial biomass-N (μg g⁻¹ dry soil).

^a Mean values of all four main plot strategies.

^b Pairwise mean comparison between all eight treatments including fallow (FA), field vegetable (FV), hay (HA) and high tunnel (HT) without (-C) or with compost (+C) application and values shown are averaged over four replicates and three sampling times. Different letters indicate significant differences between the strategies. ns: not significant ($P > 0.05$).

Table 3

Correlation coefficients among soil properties, nematode trophic groups and dominant c–p (colonizer–persister) class, and tomato yield measured in 2006. Bold numbers indicate significant correlation at $P < 0.05$.

Nematode trophic group/c–p class	Soil properties								Tomato yield
	BD	TOM	POM	MAOM	NH ₄ ⁺ -N	NO ₃ ⁻ -N	DON	MB-N	
Bacterivores									
C–p 1	–0.28	0.04	0.57	0.62	0.00	0.27	0.16	0.29	0.13
C–p 2	–0.39	0.15	0.55	0.67	0.04	0.38	0.01	0.47	0.51
Total	–0.37	0.12	0.59	0.70	0.01	0.37	0.06	0.45	0.46
Fungivores	–0.19	0.20	0.23	0.35	0.20	0.18	–0.15	0.39	0.38
Plant-feeders	–0.19	0.12	0.29	0.28	0.25	0.18	–0.11	0.39	0.38
Omnivore + predatory	–0.29	0.02	0.22	0.10	–0.14	0.28	–0.12	–0.05	–0.10
Total nematodes	–0.35	0.15	0.57	0.66	0.06	0.34	0.01	0.48	0.47
Tomato yield	–0.06	0.32	0.15	0.35	0.18	0.07	0.20	0.41	–

BD: soil bulk density, TOM: % total organic matter, POM: particulate organic matter (0.05–2 mm), MAOM: mineral associated organic matter (<0.05 mm), and mineral-N (NH₄⁺-N and NO₃⁻-N), DON: dissolved organic-N, and MB-N: microbial biomass-N ($\mu\text{g g}^{-1}$ dry soil).

the nature of organic matter added to the soil. Depletion in labile organic matter causes a decline in enrichment opportunists (c–p 1 bacterivores) (Ferris and Matute, 2003). However, the presence of recalcitrant high C/N organic matter initially favors only fungivores and c–p 2 bacterivores (Ferris et al., 2001). Addition of labile organic matter coupled with an increase in soil temperature inside high tunnels compared to the outside open field plots, may have resulted in rapid increase in microbial activity and consequently c–p 1 bacterivores (Bakonyi and Nagy, 2000; Ferris and Matute, 2003).

HA and HT plots without compost showed a similar level of c–p 2 bacterivores as those with compost but there was no increase in c–p 1 bacterivores. We speculate that organic material additions from the roots of mixed hay species and roots of vegetable crops inside high tunnels, respectively, may have added decaying matter favoring primarily c–p 2 bacterivores. On the other hand an increase in c–p 1 bacterivores and corresponding increase in c–p 2 in compost amended plots may indicate a level of succession. We conclude that continuous addition of well decomposed manure causes an increase in c–p 1 bacterivores while incorporation of hay or other crop roots into the soil as undecomposed organic matter increases c–p 2 bacterivores and fungivores. The EI values however, were not affected by compost application. EI is a measure of the abundance of enrichment opportunists relative to the abundance of basal taxa (Ferris et al., 2001). The increase

in the abundance of general opportunists masked the enrichment opportunist bacterivores (c–p 1) and reduced the overall level of EI.

Greater abundance of high c–p value nematodes like omnivores and predatory nematodes would mean a higher SI indicating greater trophic links in the soil food web (Ferris et al., 2001). SI levels were moderate to low throughout our study period except for HA in 2005. HA plots were not cultivated until the spring of 2006 and had higher abundance of omnivore and predatory nematodes compared to other strategies undergoing frequent cultivation. However, a decline in SI was observed even in HA plots following tomato production in 2006. Therefore, higher SI values observed in HA plots, possibly due to a lack of tillage until 2005, rapidly declined in 2006 following the incorporation of hay, which could possibly correlate with sensitivity of high c–p value nematodes to tillage-associated disturbance (López-Fando and Bello, 1995; Freckman and Ettema, 1993; Fiscus and Neher, 2002). Further, SI was lowest in HT plots where soil disturbance was most frequent, soil temperatures frequently highest and soil moisture restricted primarily to crop rows. These associations may help explain why compost incorporation alone is insufficient to increase trophic links in soil food webs (Berkelmanns et al., 2003; Briar et al., 2007a). Cheng and Grewal (2009) reported that compost addition did not significantly alter the structure of the soil food web in either topsoil or subsoil plots under turfgrass. We hypothesize that build up of higher c–p value nematodes (omnivores or predatory) is a slow process as observed in HA plots while a sudden physical disturbance such as cultivation quickly reduces their populations.

Soil decomposition processes are carried out primarily by soil microbes (Lundquist et al., 1999; Gunapala and Scow, 1998; Alon and Steinberger, 1999) but the primary function of microbial grazers, including free living nematodes, is to enhance nutrient mineralization (Griffiths, 1994; Bardgett et al., 1999; Chen and Ferris, 1999). The positive association of bacterivores with microbial biomass in our study suggests a potential for slow nutrient release and reduced leaching in the system dependent on organic matter inputs only (Dalal, 1998; Friedel and Gabel, 2001).

Plant-feeding nematodes, which are mainly influenced by the presence of host plants (Ferris et al., 1996; Cadet et al., 2003) were favored by the HT and HA strategies. Continuous presence of roots in both HA and HT may explain higher populations of plant-feeding nematodes in these systems than the FA and FV strategies. Application of compost did not reduce the abundance of plant-feeders as noted in other studies where endoparasitic nematodes such as *Meloidogyne incognita* and *Pratylenchus* spp. were reduced by the application of organic soil amendments (Abawi and Widmer, 2000; Riegel and Noe, 2000). However, plant-feeding nematode genera in the present study were mainly either ectoparasitic or weak root hair feeders belonging to Tylenchidae except for low abundance of *Pratylenchus*. The feeding habits of Tylenchidae nematodes are not

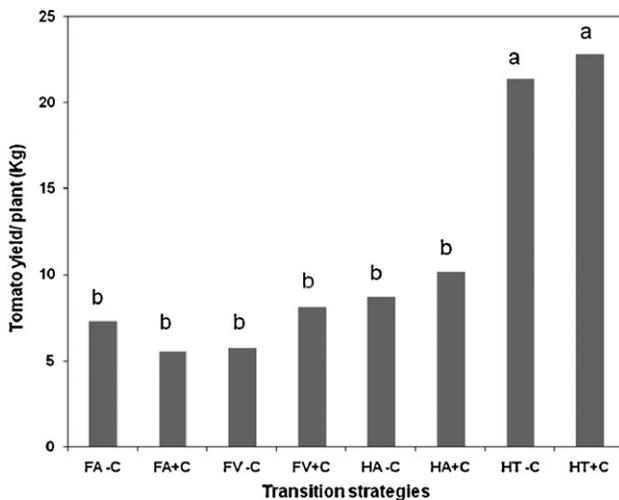


Fig. 2. Tomato yield (kg/plant) in the four organic transition strategies including tilled fallow (FA), field vegetable (FV), hay (HA) and high tunnel (HT) without (–C) or with compost application (+C) measured in 2006. Different letters indicate significant differences at ($P < 0.05$) between the treatments using the LSD mean comparison test.

properly understood (Yeates et al., 1993; Ferris and Bongers, 2006). They are considered to be either fungal-feeders or root hair feeders (Yeates et al., 1993; Okada et al., 2002).

In conclusion, this research provided an opportunity to compare the effects of compost incorporation under different organic transition strategies on soil properties and the nematode community. Compost incorporation appears to strongly affect physical, chemical and biological factors and, overall, the soil food web. Compost-amended plots were generally rich in nitrogen, microbial biomass and organic matter, with a corresponding increase in free-living nematodes dominated by bacterivores compared to the non-amended plots. Higher N may not be the sole product of nematode activity but it may be a manifestation of the responses of soil organisms with similar feeding habits such as protozoa (Ferris et al., 2001). Previous studies have quantified and shown substantial contribution of nematodes to N mineralization (Ferris et al., 1998). Modification in the soil environment using high tunnel enclosures and hay incorporation may have provided more conducive conditions for the bacterial decomposition pathways. There was an increase in bacterial feeders, although fungal feeders (fungal decomposition) remained at appreciable levels both in HT and in HA plots. Our results suggest that maintaining the soil food web in a biologically-active state during the cold period of the early spring months in northern Ohio climatic conditions using high tunnels may have increased N availability for the subsequent tomato crop. Thus, the observed increase in tomato yield in HT plots compared to the other strategies was most likely due to the combination of enhanced N availability and season extension.

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