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Influences of organic and synthetic soil fertility amendments on nematode trophic groups and community dynamics under tomatoes

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Abstract

Research was conducted to examine the effects of organic and synthetic soil amendments and tillage on nematode communities in field soils planted to tomato (*Lycopersicon esculentum*) at two locations. The experimental design was a replicated split plot with chisel-plow tillage and bare-soil or chisel-plow tillage and surface mulch with wheat straw as main plots, and soil amendments of synthetic fertilizer, composted cotton-gin trash, swine manure, or a rye-vetch green manure as subplots. Tillage did not affect free-living or plant-parasitic nematode community dynamics, but soil amendments had a large impact on nematode community structure and diversity. Populations of bacterivorous nematodes mainly in the Rhabditidae and Cephalobidae, and fungivorous nematodes were greater after planting in soils amended with swine manure, composted cotton-gin trash, or rye-vetch, than in soils amended with synthetic fertilizer at both locations. Populations of nematodes in these trophic groups decreased through time in each year. Populations of *Meloidogyne incognita* in soil were not affected by soil amendments, but increased through time at each location. Root-gall indices were lower in plots containing swine manure or cotton-gin trash than in those with synthetic fertilizer or rye-vetch during the second season. The combined nematode maturity index values were greater at planting in soils amended with rye-vetch or fertilizer than in soils with swine manure and composted cotton-gin trash. Shannon's diversity index decreased over time for both years at one location, regardless of soil amendment. At the second location, the Shannon's diversity index decreased only in the second year. Use of descriptive indices, including the Enrichment index, structure index, and channel index provided useful information about the effects of organic amendments on the structure of nematode communities in tomato field soils.

Keywords: Food web; Maturity index; Nematode ecology; Organic amendments; Trophic dynamics

1. Introduction

Nematodes play a major role in decomposition and nutrient cycling in soil food webs. These organisms are the most abundant multi-cellular organisms in terrestrial and aquatic ecosystems (Bongers and Bongers, 1998). Plant-parasitic nematodes are herbivores and thus primary consumers. Bacterial- and fungal-feeding nematodes are common secondary consumers. Predatory and omnivorous nematodes are tertiary consumers (Beare et al., 1992). Although nematodes represent a relatively small amount of biomass in soil, their presence across many trophic levels in soils is vitally important in soil environments

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and ecosystem processes (Barker and Koenning, 1998; Ingham et al., 1986).

Organic soil amendments can have large effects on plant-parasitic nematodes dynamics (Castagnone-Sereno and Kermarrec, 1991; Crow et al., 1996; McSorley and Frederick, 1999; McSorley and Gallaher, 1995, 1996, 1997; Neher, 1999). The plant-parasitic nematode *Meloidogyne incognita* was reduced in soils amended with different organic substrates, and the reduction was attributed to the release of ammoniacal nitrogen (Castagnone-Sereno and Kermarrec, 1991; Crow et al., 1996). Reductions in nematode populations occurred when chitin was added to soil infested with plant-parasitic nematodes (Hallmann et al., 1999). Chicken manure, summer cover crops or green manures can also suppress plant-parasitic nematodes (Abawi and Widmer, 2000; McSorley et al., 1999; Viaene and Abawi, 1998).

Little research has examined the effects of soil amendments, green manures or cropping systems on nematode communities and nematode trophic group dynamics. Populations of bacterivorous and fungivorous nematodes in soils increased with addition of green manures and populations remained high for up to 6 months after soil amendment (McSorley and Frederick, 1999). Crop species influenced nematode communities to a greater extent then management systems in a comparative study of organic and conventional field soils in North Carolina (Neher, 1999). Soils under organic and conventional management production in California showed little difference in bacterivore populations or total nematode populations over time, but changes in genera of bacterivores were noted (Ferris et al., 1996). Numbers of bacterivorous nematodes tend to increase after organic amendments are applied to soil since bacterial populations that provide a food base are greater after application of organic amendments (Bongers and Ferris, 1999; Bouwman and Zwart, 1994; Ferris et al., 1996; McSorley and Frederick, 1999; McSorley and Gallaher, 1996; McSorley et al., 1998). Bacterivorous nematodes tend to decrease over time as the food base declines in soils. Bacterivorous nematodes in the Rhabditidae increased dramatically in response to compost amendments in orchard soils in Florida, whereas nematodes of the Plectidae were not affected (Porazinska et al., 1999).

Disturbance of soils can have a tremendous impact on nematodes and soil food-web dynamics. Disturbances, such as tillage, can cause shifts in soil microbial communities. Notillage and surface-litter placement benefit fungi over bacteria, thus shifting the bacterial-based food web in conventional-tilled soils to a fungal-based food web (Wardle et al., 1995). Consequently, greater numbers of fungivorous nematodes are found in soils from no-till fields, whereas greater numbers of bacterivorous nematode are found in soils from fields that were conventionally tilled by moldboard plow, disking and rotary tilling (Parmelee and Alston, 1986). Nematode communities also differ in fields of annual versus perennial crops or pastures where disturbance regimes are variable. Higher plant-parasite index values occurred in soils from perennial crops or pastures than in soils from tilled crop fields (Neher and Campbell, 1994).

Nematode maturity indices have been developed that integrate the functional roles and life history strategies of nematodes in soils (Bongers, 1990). Nematodes that have short life cycles reproduce quickly, have large nutrient requirements and are considered colonizers (*r* strategists) and thus, have a low colonizer–persister (c–p) value. Long-lived, slowly reproducing nematodes with lower nutrient requirements are considered persisters (*K* strategists) and have higher c–p values (Bongers, 1990; Bongers and Ferris, 1999). The latter are more sensitive and require longer to recover from disturbances. The maturity indices utilize a nematode family's fecundity, nutritional requirements, and life strategies (*r* versus *K*) and can be an important indicator of the effects of disturbance on soil ecosystems (Bongers, 1990; Bongers and Bongers, 1998; Bongers and Ferris, 1999). Nematodes are identified to genus and assigned a colonizer–persister (c–p) number from 1 to 5 based on fecundity, life cycle, and nutritional requirements of genus (Bongers, 1990). Lower c–p values correspond with *r* strategists whereas higher c–p values correspond with *k* strategist (Bongers, 1990). Formulae can be used to calculate combined maturity indices for both free-living and plant-parasitic nematodes ($\sum$MI), for free-living nematodes (MMI), for plant-parasitic nematodes (PPI) and for the non-opportunistic nematodes of c–p groups 2–5 (MI25) (Bongers, 1990). Maturity indices have been used as ecological indicators of disturbance and a

recent study suggests that the maturity index of nematode communities may also provide a useful measure of nutrient cycling (Bongers and Ferris, 1999; Porazinska et al., 1999). Weighted indices, such as the basal index (BI), enrichment index (EI), structure index (SI), and channel index (CI), provide additional information about the nematode community structure in stressed, enriched, stable structured, and decomposition environments, and provide important information on the dynamics of soil food webs (Ferris et al., 2001).

Our study was designed to evaluate the interaction of disturbance (chisel-plow tillage on bare-soil versus chisel-plow tillage followed by surface mulch), and soil fertility amendments (synthetic versus organic) on the dynamics of free-living and plant-parasitic nematodes communities in field soils planted with tomato. Preliminary reports of portions of the research have already been published (Bulluck et al., 1999; Bulluck, 2000).

2. Materials and methods

2.1. Field plot design

This research was conducted in the summers of 1997 and 1998 at two field experiment station locations. One experiment was located at the Center for Environmental Farming Systems (CEFS), Goldsboro, NC. The soil was a Lakeland series loamy sand soil (81% sand, 12% silt, and 7% clay, pH 5.7, <0.5% OM). The second experiment was located at the Horticultural Crops Research Station (HCRS), Clinton, NC on an Orangeburg sandy loam (77% sand, 17% silt, and 6% clay, pH 5.6, <0.5% OM).

The experimental design was a split plot with either tillage on bare soil or tillage followed by surface mulch with wheat straw as main plots, and soil amendments including either synthetic fertilizer, composted cotton-gin trash, swine manure, or a rye-vetch cover crop as subplots. The same treatments were designated to the same individual plots in both locations in 1997 and 1998. Rates of each soil amendment were standardized to obtain 112 kg plant-available nitrogen per hectare. Each experimental unit consisted of six 7.6 m long rows at both locations. Granulated dolomite lime was applied once at the beginning of the experiment at a rate of 2511 kg/ha to obtain a soil pH of approximately 6.2 at both sites. In the fall of 1996 and 1997, a rye-vetch cover crop was planted in designated plots at a rate of 56 kg/ha winter rye and 28 kg/ha hairy vetch. Soils were amended with synthetic fertilizer (112 kg/ha), composted cotton-gin trash (83 metric tonnes wet weight/ha), swine manure (33 metric tonnes wet weight/ha), or a rye-vetch green manure cover crop that was planted in the fall and flail-mowed and incorporated in the soil in the spring of each year. Incorporation of amendments was done with a Ferguson Tillovator, with a 1.6 m bed shaper (11 April 1997 and 27 April 1998 at CEFS and 14 1997 and 28 May 1998 at HCRS). Two weeks after soil amendments, tomatoes (*Lycopersicon esculentum* var. Rio Colorado) were planted in single rows at a spacing of 30 cm on 1.6 m centers (8 May 1997 and 15 May 1998 at CEFS, 2 June 1997 and 11 June 1998 at HCRS). Overhead irrigation was utilized as needed (2.5–3.0 cm per week without adequate rain). All plots were tilled for weed control once prior to application of surface mulch, and bare-soil plots were tilled an additional two or three times until tomato plants were too large for a tractor to clear. Wheat straw was applied as mulch to the surface of plots, 2–3 weeks after transplanting.

Synthetic fertilizers for this experiment were obtained from Royster-Clark (Tarboro, NC) and consisted of a 10:10:10 formulation of NH_4NO_3 (10% plant available nitrogen), P_2O_5 (10% plant available phosphorus) and K_2O (10% plant available potassium).

Composted cotton-gin trash was obtained from Cotton Ginning and Sales in Goldsboro, NC. The material, consisting of cotton bolls, stems, seeds and fiber from cotton was mixed with small amounts of soil at least twice during the period of composting. Cotton-gin trash contained an average of 0.12% plant-available nitrogen, 0.24% phosphorus, and 0.60% potassium (dry weight) (analysis by A&L Laboratories, Richmond, VA). Cotton-gin trash also contained other nutrients, including 1.66% calcium, 0.33% magnesium, and 0.28% iron (dry weight basis).

Swine manure waste was obtained from a swine waste treatment system installed at the Center for Environmental Farming Systems in Goldsboro, NC. Swine waste biosolids consisted of feces, hair and corn meal–soy meal feed and were not composted.

The solid waste from the swine house was screened through a 1.6 mm wire-mesh screen, placed in a manure spreader, and stored usually for less than a week prior to field application. We used raw biosolids because composted swine manure was unavailable in NC at the time the research was conducted. Swine-waste biosolids contained an average of 0.34% plant available nitrogen, 0.12% available phosphorus, and 0.14% potassium on a wet weight basis (15% dry matter). Calcium (0.56%), magnesium (0.12%), and iron (0.05%) (wet weight basis) were also present in the swine manure.

2.2. Nematode analyses

Six soil cores (1.9 cm diameter and 20 cm deep) were removed for nematode assays from each of the four interior rows of six-row plots in the plant beds. The 24 soil cores were sampled in a random pattern down each row, mixed into a single plastic bag, placed in coolers with ice and then stored at 10 °C on the same day until processed. Soil samples were taken approximately 2 weeks after planting (20 May 1997 and 1 June 1998 at CEFS, 16 June 1997 and 25 June 1998 at HCRS), and at harvest (19 August 1997 and 21 August 1998 at CEFS, 19 August 1997 and 24 August 1998 at HCRS).

Nematodes were extracted from 500 cm^3 of soil, using a combination of a semi-automatic elutriator with a 400 mesh sieve and sugar centrifugation (Byrd et al., 1976; Barker et al., 1985). All soil extractions were completed within 3 weeks of soil sampling. Total numbers of nematodes/500 cm^3 of soil were determined (but not corrected for extraction efficiency) from each treatment–replicate combination, and nematodes were identified to trophic group using esophageal and general morphology (Bongers, 1988). Once trophic group analyses were accomplished, samples were preserved, using the hot formalin technique, for identification to genus at a later time (Barker et al., 1985).

A 0.2 ml subsample from each preserved sample was placed inside a 15 mm × 45 mm paraffin wax rectangle on a standard glass microscope slide, and then covered with a 22 mm × 50 mm glass cover slip. The slide was sealed by application of heat (from hot plate or flame), and 100–200 individual nematodes were identified to genus from each sample, using the English key to Bonger's "De Nematoden van Nederland" and assigned a c–p value (Bongers, 1988). Four nematode maturity indices were also calculated (Bongers, 1990). The formula for calculating the maturity index: for free-living nematodes is $MI = \left(\sum v_i f_i\right)/n$, where v_i is the c–p value for the nematode family i, f_i is the frequency of nematode family i, and n is the total number of individual nematodes in the sample; for plant parasites is $PPI = \left(\sum v_i f_i\right)/n$ where v_i is the c–p value for the plant-parasitic nematodes family i, and f_i is the frequency of plant-parasitic nematodes family i, and n is the total number of individual nematodes in the sample; and for the combined maturity index for free-living and plant parasites is $\sum MI = \left(\sum v_i f_i\right)/n$, where v_i is the c–p value for the free-living or plant parasitic nematode family i; and f_i is the frequency of the nematode family i and n is the total number of individual nematodes in the sample; for free-living nematodes excluding opportunistic colonizers (c–p = 1) $MI25 = \left(\sum v_i f_i\right)/n$, where v_i is the c–p value for the nematode family i, f_i is the frequency of nematode family i, and n is the total number of individual nematodes in the sample, with all nematodes from c–p = 1 group excluded from analysis. These values are all expressed as the weighted means. The BI, EI, and SI were also calculated according to Ferris et al. (2001), with basal components (b) of the food web (fungal and bacterial feeders in the c–p = 2 guild) calculated as $b = \sum k_b n_b$ where k_b is the weighted constant for the guild, and n is the number of nematodes in that guild. Enrichment (e) and structure (s) components were similarly calculated, using nematodes guilds indicative of enrichment (bacterivorous nematodes in c–p = 1, and fungivores of c–p = 2), and those guilds supporting structure (bacterivorous nematodes in c–p = 3–5, fungivores c–p = 3–5, omnivores of c–p = 3–5, and predatory nematodes of c–p = 2–5). The EI is calculated as $100 \times (e/(e + b))$, and the SI as $100 \times (s/(s + b))$. The CI is calculated as the proportion of fungivores in c–p = 2 (fun2) within the decomposer guilds of bacterivorous and fungivorous nematodes in the c–p = 1 (bac1) group and fun2 as follows: $100 \times (0.8\text{fun2}/(3.2\text{fun2} + 0.8\text{bac1}))$. The coefficients are the k_e enrichment weightings for the respective guilds (Ferris et al., 2001). These indices provide information about the structure and enrichment of the soil food web and the channels through which decomposition occurs.

Root-knot nematode galls were indexed on plants by destructively sampling 10 tomato plants (five each from outside rows) per plot in July of 1997 and 1998 at CEFS. A percentage of galled roots was estimated and adjusted to a 0–10 scale where 1 = 10% galled roots and 10 = 100% galled roots.

2.3. Biodiversity, richness and evenness

Nematode diversity, richness, and evenness was measured with three indices: the Shannon diversity index ($H' = -\sum P_i \ (\ln P_i)$, where P_i is the proportion of the genus n_i in the total nematode community, n); the Margalef formula for nematode community richness $\{\text{Margelef} = G - 1/\ln n\}$, where G is the total number of genera in sample, and Pielou's evenness formula for nematode community evenness (H'/G) (Kennedy and Smith, 1995; Shannon and Weaver, 1949). Thus for all indices, genera were used rather than species for calculation.

Statistical analyses of all data were conducted using SAS 7.0 (SAS Institute, Cary, NC). The general linear model (PROC GLM) was used to obtain F values for the split plot experimental design using the appropriate error terms in the model. Variance in nematode count data was normalized using $\text{Log}_{10}\, x + 1$ transformation, and variance in proportion community composition was normalized with the arcsine transformation. Maturity, diversity, richness, and evenness indices were analyzed without transformation. Least significant differences (LSD), when given, are derived from confidence limits from the least squares (ls) means procedure. Orthogonal contrasts were used to compare variability within and between sampling times over the course of the experiment. Because of major differences in nematode community structure at the two experimental locations, independent statistical analyses were conducted for each location and data are presented separately.

3. Results

3.1. Nematode trophic dynamics

Thirty-six genera of nematodes were identified in soil samples from CEFS in 1997 and 27 genera of nematodes were identified in 1998. A total of 36 genera of nematodes were identified in soil samples from HCRS in 1997 and 30 in 1998. Bacterivorous nematodes were predominant in these tomato field soils (Table 1). Between 11 and 15 bacterivorous genera representing nine bacterivorous nematode families were present at all sample times (Table 1). The bacterivorous nematodes observed are indicated in Table 1. Fungivorous nematodes at both CEFS and HCRS included the genera *Aphelenchoides* spp., *Aphelenchus* spp., *Filenchus* spp., and occasionally *Psilenchus*. Omnivorous nematodes observed at both locations mainly consisted of *Eudorylaimus*, but also included *Prismatolaimus*, *Aporcelaimus*, *Mesodorylaimus*, and occasionally *Prodorylaimus*, *Discolaimus*, *Tylencholaimus*, and *Pungentus*. Predatory nematodes were rare, and included *Mylonchus*, *Mononchus*, and *Prionchulus* (Table 1). No differences were discernable among predatory nematode genera over time or with treatments since the numbers of predatory genera recovered were low with the elutriation process (Tables 2 and 3). Plant parasitic nematodes at both CEFS and HCRS consisted mainly of *M. incognita*, *Pratylenchus*, *Tylenchorhynchus*, *Hoplolaimus*, *Helicotylenchus*, and occasionally *Trichodorus*, *Paratrichodorus*, *Paratylenchus*, *Mesocriconema*, and *Xiphinema americana* (Table 1).

Neither soil amendments nor tillage had a consistent impact on numbers of most plant-parasitic nematodes but numbers of specific genera changed over time. Populations of *M. incognita* were not affected by soil amendment, but increased from planting to harvest in both years at both locations (Tables 2 and 3, Fig. 1). At HCRS, numbers of nematodes in the genus *Pratylenchus* were lower in soils amended with rye-vetch than other amendments at the harvest sample time in both years (Table 3). Numbers of *Helicotylenchus* were greatest in soils amended with swine manure or composted cotton-gin trash at CEFS in both years (Table 2). The dominant species of plant parasitic nematode at both locations was *M. incognita*. *Helicotylenchus*, and nematodes of the family Trichodoridae also occurred at CEFS, and *M. incognita*, *Pratylenchus*, and nematodes of the family Trichodoridae occurred at HCRS.

Soil amendment and sample time had a significant effect on certain nematode genera within the bacterivorous trophic group (Tables 2 and 3). Rhabditid

Table 1
Nematode genera identified in two field locations at the Center for Environmental Farming Systems (CEFS), Goldsboro, NC, and the Horticultural Crops Research Station (HCRS), Clinton, NC in 1997 and 1998

Bacterivores[a]	Plant parasites	Fungivores	Omnivores	Predators
CEFS				
(*Meso*)*Rhabditis*[b]	*Meloidogyne*	*Aphelenchoides*	*Eudorylaimus*	*Mylonchus*
Cephalobus[c]	*Helicotylenchus*	*Filenchus*	*Aporcelaimus*	*Mononchus*
Heterocephalobus[c]	*Hoplolaimus*	*Aphelenchus*	*Mesodorylaimus*	*Prionchulus*
Acrobeles[c]	(*Para*)*Trichodorus*[d]		*Prodorylaimus*	
Eucephalobus[c]	*Tylenchorhynchus*		*Prismatolaimus*	
Acrobeloides[c]	*Pratylenchus*		*Pungentus*	
Cervidellus[3]	*Xiphinema*		*Tylencholaimus*	
Pristionchus	*Mesocriconema*			
Wilsonema	*Paratylenchus*			
Plectus				
Diploscapter				
Diphtherophora				
Diplogasteroides				
Alaimus				
Panagrobelus				
HCRS				
(*Meso*)*Rhabditis*[b]	*Meloidogyne*	*Aphelenchoides*	*Eudorylaimus*	*Mylonchus*
Heterocephalobus[c]	*Pratylenchus*	*Filenchus*	*Aporcelaimus*	*Mononchus*
Acrobeles[c]	(*Para*)*Trichodorus*[d]	*Aphelenchus*	*Mesodorylaimus*	*Prionchulus*
Cephalobus[c]	*Tylenchorhynchus*	*Psilenchus*	*Prodorylaimus*	
Eucephalobus[c]	*Helicotylenchus*		*Discolaimus*	
Acrobeloides[c]	*Hoplolaimus*		*Prismatolaimus*	
Cervidellus[c]	*Mesocriconema*		*Pungentus*	
Alaimus	*Xiphinema*			
Diploscapter				
Diplogaster				
Pristionchus				
Panagrobelus				
Plectus				
Wilsonema				

[a] Most abundant genera at top of list and least abundant at bottom of list.
[b] Family Rhabditidae.
[c] Family Cephalobidae.
[d] Family Trichodoridae.

and cephalobid nematode populations were higher initially after amendment of soils with cotton-gin trash or swine manure (Tables 2 and 3). Populations of *Diploscapter* spp., were more abundant in soils amended with swine manure than other amendments at both CEFS and HCRS (Tables 2 and 3). Most of the common bacterivorous nematodes in the Rhabditidae and Cephalobidae decreased from planting time to harvest in both years (Tables 2 and 3).

Soil fertility amendments affected gall indices caused by root-knot nematode on tomato roots at CEFS. Plants from soils containing swine manure, composted cotton-gin trash, rye-vetch and synthetic fertilizers averaged a gall index of 3.2, 4.3, 4.4, and 5.2, respectively (LSD = 1.52). Gall indices in plants from plots with swine manure were lower than gall indices in plants from plots with synthetic fertilizers in 1997. Gall indices were also lower in plants from plots with swine manure or cotton-gin trash (5.4 and 5.5, respectively) than synthetic fertilizers or rye-vetch green manure (7.2 and 7.3, respectively, LSD = 1.11) in 1998.

Table 2
Effect of soil amendment and time on numbers of nematodes within trophic groups at the Center for Environmental Farming Systems (CEFS), Goldsboro, NC, in 1997 and 1998

Trophic group	Amendment type								
	Planting[a]					Harvest[a]			
	c–p[b] value	Fert.[c]	Cotton-gin trash	Swine manure	Rye-vetch	Fert.	Cotton-gin trash	Swine manure	Rye-vetch
1997									
Bacterivores									
Rhabditidae	1	137	704	3392	390	222	144	324	140
Cephalobidae	2	355	1157	2664	1740	190	347	497	235
Diploscapter	1	3	64	480	25	30	16	89	0
Other bacterivores		73	73	454	87	164	134	88	134
Fungivores	2	352	823	2078	1802	138	333	356	302
Omnivores									
Eudorylaimus	4	35	166	119	77	92	173	119	189
Other omnivores	5	36	59	30	163	12	0	26	14
Plant parasites									
Meloidogyne	3	2	15	5	46	3770	4016	3982	5983
Helicotylenchus	3	314	599	417	169	1282	3504	3900	1986
Hoplolaimus	3	492	633	307	527	54	57	46	38
Other plant parasites		31	92	64	276	202	351	324	212
Predators		3	11	26	11	0	0	0	0
1998									
Bacterivores									
Rhabditidae	1	181	1037	1624	589	170	414	582	205
Cephalobidae	2	207	566	1238	535	306	756	606	667
Diploscapter	1	0	15	354	0	12	0	38	21
Other bacterivores		17	1	34	7	0	20	0	0
Fungivores	2	112	214	562	544	40	16	102	40
Omnivores									
Eudorylaimus	4	107	180	153	133	82	70	189	118
Other omnivores	5	46	52	102	41	4	0	0	9
Plant parasites									
Meloidogyne	3	424	452	276	385	5977	10254	8922	7597
Helicotylenchus	3	393	1162	904	710	503	1633	1628	563
Other plant parasites		190	262	309	351	287	194	328	380
Predators	4	1	4	0	0	0	0	0	0

[a] Average numbers of nematodes/500 cm^3 of soil for each amendment type at planting and harvest ($n = 8$).
[b] The c–p values for nematode families after Bongers (1990). Used in maturity index calculations.
[c] Soils were amended with synthetic fertilizers (Fert.), composted cotton-gin trash, swine manure, or rye-vetch green manure.

3.2. Numbers and relative abundance of nematode trophic groups

Numbers of bacterivorous nematodes were initially more numerous after soil amendment with swine manure in both years than in soils amended with synthetic fertilizers (Fig. 2A and B). Numbers of bacterivorous nematodes were more abundant at the end of the second year at both locations in soils amended with composted cotton-gin trash than soils amended with synthetic fertilizers (Fig. 2A and B).

Table 3
Effect of soil amendment and time on numbers of nematodes within trophic groups at the Horticultural Crops Research Station (HCRS), Clinton, NC, in 1997 and 1998

Trophic group	Amendment type								
	Planting[a]					Harvest[a]			
	$c-p$[b] value	Fert.[c]	Cotton-gin trash	Swine manure	Rye-vetch	Fert.	Cotton-gin trash	Swine manure	Rye-vetch
1997									
Bacterivores									
Rhabditidae	1	66	1509	1308	164	762	448	913	570
Cephalobidae	2	354	1368	1840	580	338	576	625	448
Diploscapter	1	2	117	13	0	0	3	10	0
Other bacteriovores		40	10	22	18	48	61	47	97
Fungivores	2	223	545	887	358	372	656	748	769
Omnivores									
Eudorylaimus	4	142	353	186	180	279	271	378	250
Other omnivores	5	35	94	63	70	35	56	87	53
Plant parasites									
Meloidogyne incognita	3	0	0	4	0	0	92	17	761
Pratylenchus	3	0	0	7	0	164	151	298	78
Trichodoridae	4	47	70	82	292	104	53	76	87
Other plant parasites		47	0	22	147	45	54	78	117
Predators	4	1	10	19	6	22	24	24	13
1998									
Bacterivores									
Rhabditidae	1	297	657	1186	684	259	350	318	229
Cephalobidae	2	689	951	1786	1033	475	577	615	414
Diploscapter	1	25	22	804	34	0	58	23	5
Prismatolaimus	3	28	39	57	30	10	36	23	49
Other bacteriovores		33	39	72	35	10	40	52	55
Fungivores	2	396	697	615	489	246	234	191	262
Omnivores									
Eudorylaimus	4	191	234	484	291	164	97	137	206
Other omnivores	5	46	101	127	140	16	31	57	77
Plant parasites									
Meloidogyne incognita	3	28	54	9	27	1325	1803	1797	2429
Pratylenchus	3	80	160	35	40	976	956	787	182
Tylenchorhynchus.	3	21	162	99	211	18	16	43	283
Trichodoridae	4	25	83	64	174	125	48	30	53
Other plant parasites		8	5	50	38	42	18	24	68
Predators	4	6	8	0	16	0	0	10	20

[a] Average numbers of nematodes/500 cm^3 of soil for each amendment type at planting and harvest ($n = 8$).
[b] The c–p values for nematode families after Bongers (1990). Used in maturity index calculations.
[c] Soils were amended with synthetic fertilizers (Fert.), composted cotton-gin trash, swine manure, or rye-vetch green manure (R-V).

Numbers of fungivorous nematodes were also higher at planting in 1997 in soils amended with organic amendments than in those with synthetic fertilizer at both locations (Fig. 2C and D). Numbers of fungivorous nematodes remained higher in plots amended with organic amendments than in soils containing synthetic fertilizer at the end of the experiment at CEFS, but numbers were not statistically different

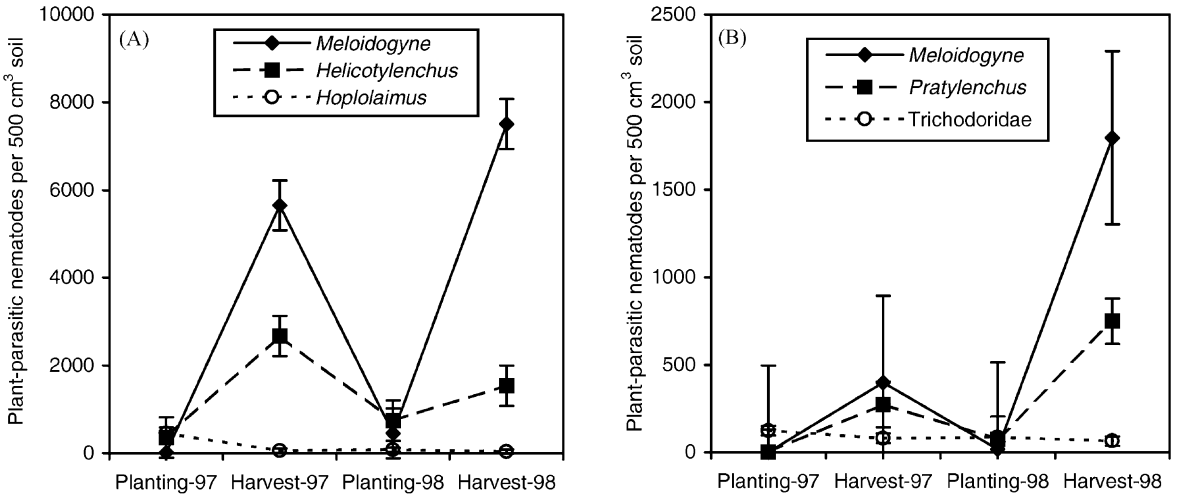

Fig. 1. Number of plant-parasitic nematodes/500 cm^3 soil sample ($n = 32$) over time at (A) Center for Environmental Farming Systems (CEFS), Goldsboro, NC (LSD = 1004 nematodes/500 cm^3, and (B) the Horticultural Crops Research Station, Clinton, NC (LSD = 348 nematodes/500 cm^3. Note difference in scale.

at HCRS. No consistent effects of soil amendment or time on specific genera within the fungivorous trophic group were observed.

The relative abundance of bacterivorous nematodes at CEFS in 1997 was 65.6% at planting in soils with swine manure and 42.2, 43 and 31% in soils from plots containing composted cotton-gin trash, rye-vetch or synthetic fertilizers, respectively (Table 4). In contrast, at harvest at CEFS in 1997, plant-parasitic nematodes were the most abundant group in all soils regardless of soil amendment and ranged from 83 to 88% of the total community. Bacterivorous nematodes comprised a lower percentage of the total community at CEFS in 1998 than 1997, but were still greater in soils amended with swine manure than plots amended with composted cotton-gin trash, rye-vetch or synthetic fertilizers (Table 4). Similarly, in 1998, plant parasitic nematodes comprised from 88 to 91% of the nematode community at harvest, regardless of soil amendment (LSD = 11.2%). Bacterivorous nematodes were also more abundant at planting than at harvest at the HCRS in soils amended with swine manure or cotton-gin trash than synthetic fertilizer. Plant parasitic nematodes were also more abundant at harvest than at planting at HCRS in 1998, but comprised a lower percentage of the total nematode community than at the other field location at CEFS. The main effects of tillage or tillage followed by surface mulch had little impact on nematode community structure over the course of the experiment (results not shown).

3.3. Nematode maturity and food web indices

Soil amendment and time had a significant effect on the combined maturity index (Fig. 3A and B). Maturity indices increased with time in each season and were lower initially in soils from plots amended with swine manure or cotton-gin trash than rye-vetch or synthetic fertilizers at each location. The lowest $\sum$ MI were observed in plots amended with swine manure at planting in both years due to the enrichment affect of the soil amendment (Fig. 3A and B). No differences were observed in $\sum$ MI at harvest either location, nor were differences observed in the MI25's over the course of the experiment.

The EI and CI at both CEFS and HCRS were affected by soil amendment and time (Table 5, Fig. 4). The EI were greater at planting in 1997 in soils amended with swine manure and composted cotton-gin trash than synthetic fertilizers or rye/vetch green manure at both CEFS and HCRS, (Fig. 4A and B). The CI was higher at planting in 1997 in soil amended with rye-vetch green manure or synthetic fertilizers than in soils with composted cotton-gin

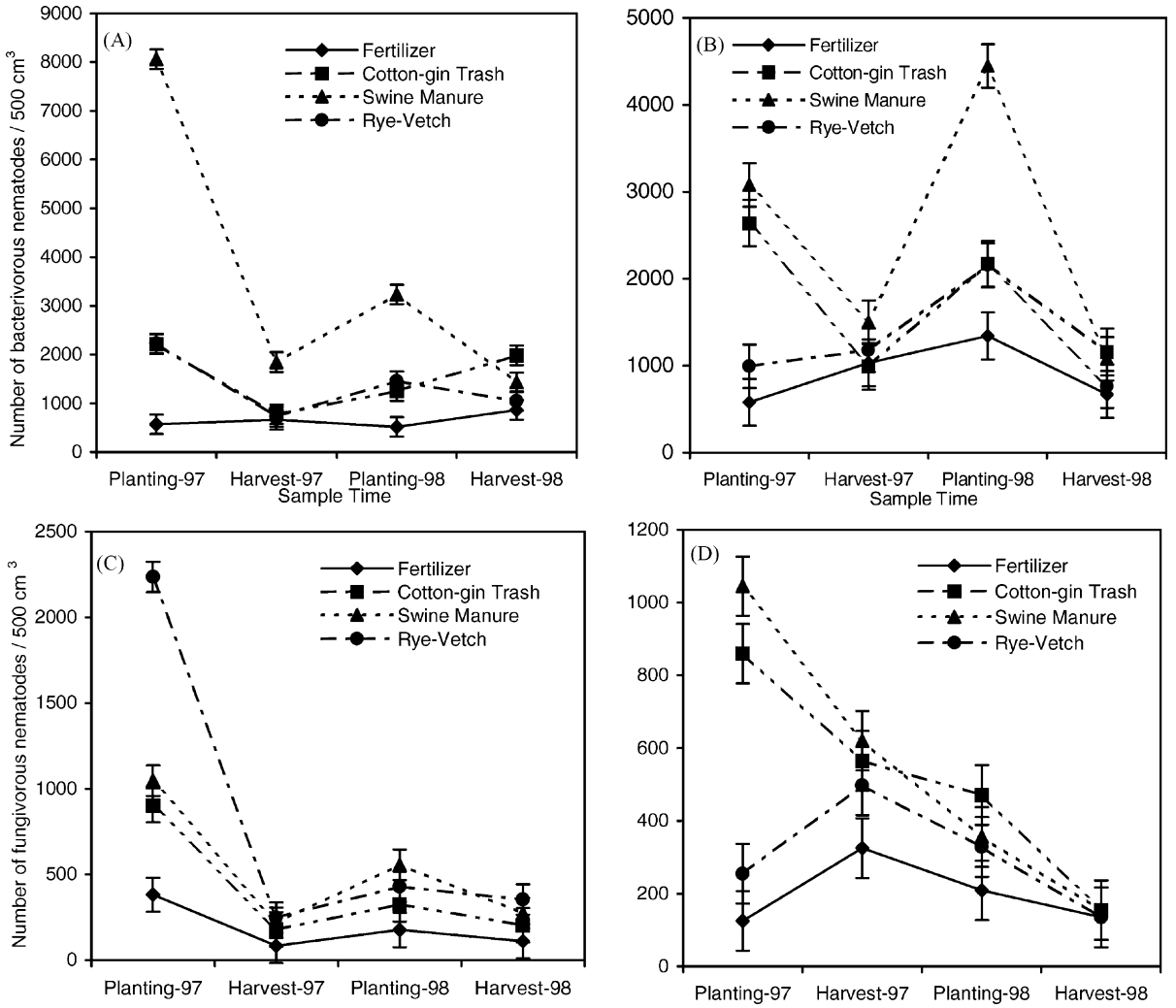

Fig. 2. Impact of time and soil amendment on numbers of bacterivorous nematodes/500 cm^3 soil at (A) CEFS, Goldsboro, NC (LSD = 203 nematodes/500 cm^3), and (B) HCRS (LSD = 269 nematodes/500 cm^3), Clinton, NC, and numbers of fungivorous nematodes/500 cm^3 soil at (C) CEFS (LSD = 89 nematodes/500 cm^3) and at (D) HCRS (LSD = 82 nematodes/500 cm^3).

trash or swine manure (Fig. 4C and D). The nematode faunal analyses (Fig. 5) reveal that the vast majority of points occupied quadrats A and B, indicating an enriched, disturbed food web with bacterial decomposition channels.

3.4. Diversity, richness, and evenness

In both years, the Shannon–Weaver index for nematode community diversity (H') was significantly affected by time at each location (Table 5). At CEFS, nematode diversity and evenness decreased over time from 1.23 to 0.75 in 1997 (LSD = 0.02) and from 1.30 to 0.55 in 1998 (LSD = 0.05). At HCRS, H' increased slightly over time from 1.35 to 1.42 in 1997 (LSD = 0.02) and decreased from 1.47 to 1.00 in 1998 (LSD = 0.03).

Nematode community evenness estimated from Pielou's evenness index was also affected by soil amendment and time at CEFS in both years, and

Table 4
Effect of soil amendment and time on the percentage of nematodes in different trophic groups in at CEFS and HCRS in 1997 and 1998

	Total community (%)				
	Amendment	Bacterivore	Fungivore	Plant parasite	Other[a]
CEFS-1997					
Planting	Fertilizer	31.0	20.9	39.9	8.2
	Cotton-gin trash	42.2	17.9	29.7	10.3
	Swine manure	65.6	18.2	7.6	8.6
	Rye-vetch	42.0	31.5	20.1	6.4
Harvest	Fertilizer	10.1	2.8	84.8	2.4
	Cotton-gin trash	6.9	3.5	87.2	2.4
	Swine manure	10.9	4.0	83.4	1.7
	Rye-vetch	5.9	4.1	87.5	2.5
LSD[b]		5.6	4.4	4.3	ns[c]
CEFS-1998					
Planting	Fertilizer	24.9	8.6	55.9	10.6
	Cotton-gin trash	41.4	6.8	45.8	6.1
	Swine manure	59.8	9.4	24.9	6.0
	Rye-vetch	34.4	17.9	42.4	5.3
Harvest	Fertilizer	6.8	0.4	91.8	1.1
	Cotton-gin trash	8.3	0.1	90.8	0.9
	Swine manure	9.8	0.9	87.9	1.5
	Rye-vetch	9.8	0.5	88.3	1.5
LSD		11.0	3.9	11.2	ns
HCRS-1997					
Plant	Fertilizer	48.1	24.8	9.5	17.6
	Cotton-gin trash	73.1	13.6	1.8	11.5
	Swine manure	70.3	19.4	3.1	7.2
	Rye-vetch	40.6	19.8	25.3	14.4
Harvest	Fertilizer	47.4	19.0	15.5	18.2
	Cotton-gin trash	44.3	26.8	13.9	15.0
	Swine manure	49.8	22.5	12.1	15.6
	Rye-vetch	36.8	28.4	21.5	13.3
LSD		13.4	8.4	7.1	ns
HCRS-1998					
Plant		58.3	17.6	11.9	12.2
Harvest		23.7	7.0	63.9	5.3
LSD		12.7	6.6	13.9	ns

[a] Other category includes both omnivorous and predacious nematodes.
[b] Least significant difference based on confidence limits from general linear models procedure in SAS 7.0.
[c] ns: not significant at the 0.05% level.

HCRS in 1997 (Table 5). Evenness of nematode genera was higher in soils amended with fertilizer or rye-vetch than soils amended with composted cotton-gin trash or swine manure at planting in 1997 and 1998 (Table 6). At harvest at CEFS, evenness was lower in all plots, regardless of soil amendment. Similarly, at HCRS, soils with synthetic fertilizers or rye-vetch had higher evenness indices at planting than plots with swine manure and composted cotton-gin trash in 1997 (Table 6). Pielou's evenness index decreased from planting to harvest in 1998 regardless of soil amendment but, at harvest, evenness indices in soils containing composted cotton-gin trash or synthetic fertilizer were higher than in plots

Table 5
Probability values for nematode trophic composition, and maturity, diversity, richness, and evenness indices at the Center for Environmental Farming Systems (CEFS), and the Horticultural Crops Research Station (HCRS) in both 1997 and 1998

Trophic group and index	Probability > F (1997)			Probability > F (1998)		
	Amendment	Time	Amendment by time	Amendment	Time	Amendment by time
CEFS						
Bacterivores	<0.01	<0.01	<0.01	<0.01	0.84	0.02
Fungivores	0.01	0.28	0.30	<0.01	<0.01	0.73
Omnivores	0.43	0.02	<0.01	0.34	0.59	0.19
Predators	0.04	0.09	0.36	0.02	0.14	0.02
Fung:bact	<0.01	0.15	0.10	0.63	0.38	0.32
$\sum$ MI (Combined)[a]	0.01	0.01	0.04	<0.01	<0.01	<0.01
MI (free-living)[b]	0.26	0.85	0.52	0.03	0.68	0.54
PPI (plant parasitic)[c]	0.03	0.08	0.09	0.35	0.06	0.16
MI25 (free-living w/o c–p = 1)[d]	0.86	0.53	0.69	0.22	0.31	0.19
Basal index (BI)[e]	0.11	0.24	0.04	0.11	0.07	0.70
Enrichment index (EI)[f]	0.04	0.39	0.02	0.03	0.02	0.78
Structure index (SI)[g]	0.11	0.09	0.83	0.37	0.43	0.18
Channel index (CI)[h]	0.02	0.44	0.01	0.05	0.06	0.60
Diversity index H' (Shannon)[i]	0.24	<0.01	0.06	0.16	<0.01	0.09
Richness (Margalef)[j]	0.79	0.23	0.53	0.44	<0.01	0.03
Evenness (Pielou)[k]	0.22	<0.01	0.01	0.11	<0.01	0.01
HCRS						
Bacterivores	<0.01	0.38	0.42	<0.01	<0.01	0.03
Fungivores	<0.01	0.53	0.03	0.03	0.10	0.76
Omnivores	<0.01	0.69	0.07	0.01	0.57	0.28
Predators	0.77	0.84	0.38	0.44	0.67	0.14
Fung:bact	0.18	0.66	0.82	0.16	0.76	0.42
$\sum$ MI (combined)[a]	<0.01	0.29	0.02	0.27	0.40	0.65
MI (free-living)[b]	0.03	0.63	0.01	<0.01	0.16	0.08
PPI (plant parasitic)[c]	0.03	0.60	0.04	0.92	0.88	0.92
MI25 (free-living w/o c−p = 1)[d]	0.04	0.10	0.06	<0.01	0.08	0.75
Basal index (BI)[e]	0.05	0.06	0.01	0.01	0.81	0.46
Enrichment index (EI)[f]	0.01	0.05	<0.01	0.13	0.50	0.07
Structure index (SI)[g]	0.04	0.04	0.12	<0.01	0.08	0.71
Channel index (CI)[h]	<0.01	0.33	<0.01	0.04	0.72	0.20
Diversity index H' (Shannon)[i]	0.07	0.05	0.07	0.84	<0.01	0.81
Richness (Margalef)[j]	0.57	0.04	0.67	0.40	0.40	0.65
Evenness (Pielou)[k]	0.04	0.97	0.03	0.634	<0.01	0.68

[a] $\sum$ MI for combined free-living and PPI is $\sum \mathrm{MI} = \left(\sum v_i f_i\right)/n$, where v_i is the c–p value for the nematode family i, and f_i is the frequency of nematode family i.

[b] PPI $= \left(\sum v_i f_i\right)/n$, where v_i is the c–p value for the plant-parasitic nematode family i, and f_i is the frequency of plant-parasitic nematode family i.

[c] MI $= \left(\sum v_i f_i\right)/n$, where v_i is the c–p value for the free-living nematode family i; and f_i is the frequency of the free-living nematode family i.

[d] MI25 $= \left(\sum v_i f_i\right)/n$, where v_i is the c–p value for the free-living nematode family i; and f_i is the frequency of the free-living nematode family i, for all free-living nematodes except those with a c–p number of 1.

[e] Basal index is calculated by $100 \times (b/(s+e+b))$ where s is the weighted proportion of the structured component of soil foodwebs, e is the weighted proportion of the enriched component of the soil food web, and b is the weighted proportion of the basal component of the soil food web (after Ferris et al., 2001).

[f] Enrichment index is calculated by $100 \times (e/(e+b))$, after Ferris et al., 2001.

[g] Structure index is calculated by $100 \times (s/(s+b))$, after Ferris et al., 2001.

[h] Channel index is calculated by 100 × (fun2/(fun2 + bac1)) where fun2 is the weighted proportion of the fungivores in the c–p = 2 group and bac1 is the weighted proportion of bacterivores in the c–p = 1 group.

[i] Shannon diversity index ($H' = -\sum P_i$ (ln P_i), where P_i is the proportion of the genus n_i in the total nematode community n).

[j] Margalef index for community richness Margelef $= G - 1/\ln n$, where G is the total number of genera in the sample.

[k] Pielou's evenness formula for community evenness $= H'/G$.

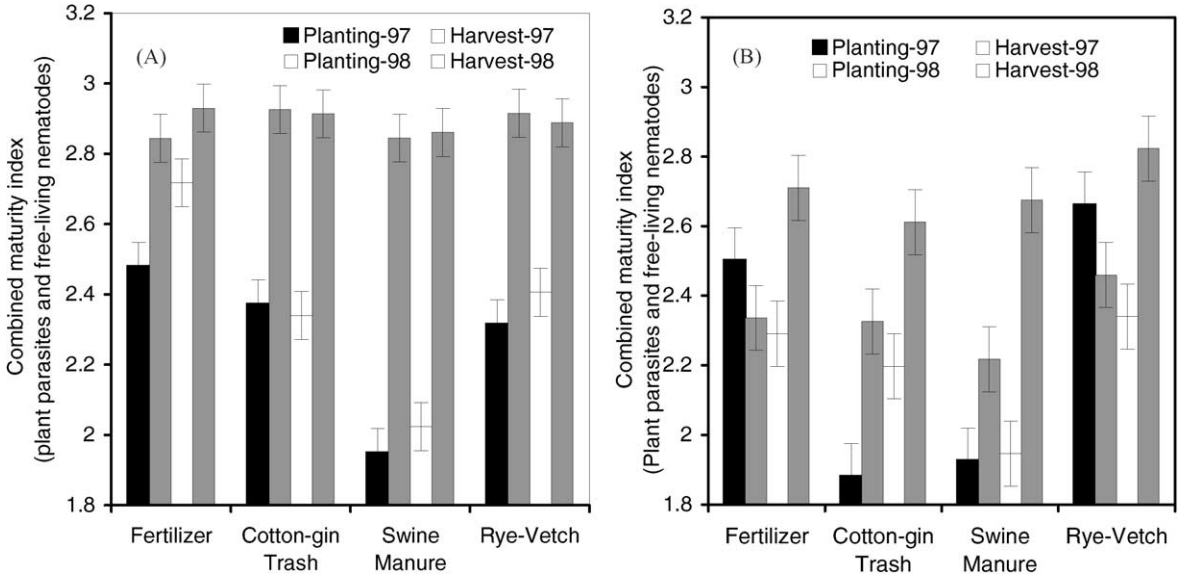

Fig. 3. Impact of soil amendment and time on Bongers' maturity index at (A) CEFS, Goldsboro, NC (LSD = 0.068), and (B) HCRS, Clinton, NC (LSD = 0.093).

Table 6
Pielou's evenness index for nematode populations at the Center for Environmental Farming Systems (CEFS) and the Horticultural Crop Research Station (HCRS) in 1997 and 1998[a,b]

Pielou's evenness	1997		1998	
	Plant	Harvest	Plant	Harvest
CEFS				
Fertilizer	0.52	0.34	0.54	0.22
Composted cotton-gin trash	0.34	0.27	0.50	0.27
Swine manure	0.38	0.36	0.53	0.32
Rye-vetch	0.51	0.31	0.59	0.29
LSD	0.03	0.03	0.02	0.02
HCRS				
Fertilizer	0.59	0.54	0.62	0.42
Composted cotton-gin trash	0.52	0.58	0.58	0.43
Swine manure	0.51	0.55	0.57	0.39
Rye-vetch	0.61	0.56	0.58	0.37
LSD	0.02	0.02	0.03	0.03

[a] Pielou's evenness formula for community evenness $= H'/G$, H' is the Shannon diversity index, $H' = -\sum P_i \ (\ln P_i)$ and P_i is the proportion of the genus n_i in the total nematode community n where G is the total number of genera in the sample.

[b] Least squared difference from general linear model procedure in SAS 7.0.

amended with swine manure or rye-vetch (Table 6). Lower trophic diversity and evenness indices can be attributed to increased populations of plant parasitic nematodes. Nematode community genera richness was unaffected by soil amendment, tillage, or surface mulch over the course of the experiment.

4. Discussion

Nematode trophic dynamics and nematode community structure were affected by organic soil amendments. In our research, rhabditid nematodes comprised the majority of bacterivorous nematodes after planting, but populations dropped precipitously over time, whereas cephalobid nematode populations decreased more slowly. Increased populations of bacterivorous nematodes can be linked directly to higher populations of bacteria that were associated with the input of organic amendments in these plots (Bulluck and Ristaino, 2001). An interesting observation is the high numbers of nematodes in the genus *Diploscapter* present in soils amended with swine manure. While these findings are previously unreported, little research has been done on the effects of swine manure

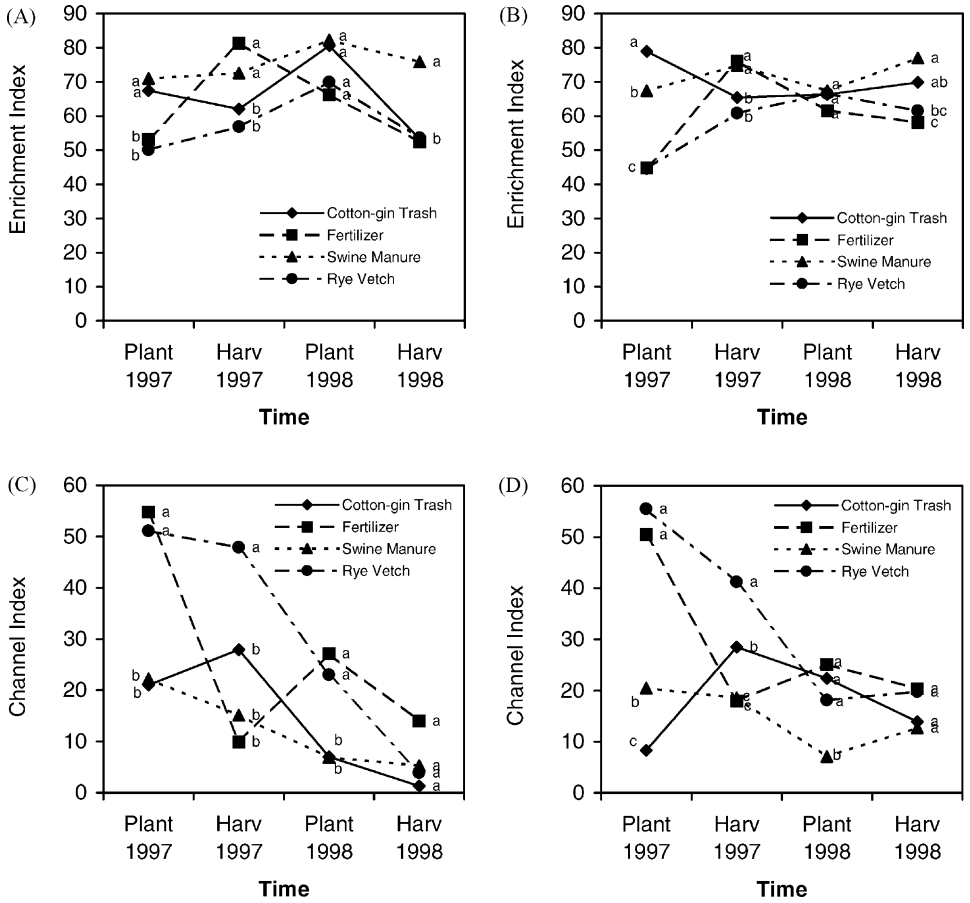

Fig. 4. Effects of soil amendment and time on the enrichment index at (A) CEFS, Goldsboro, NC (LSD = 14.65), and (B) HCRS, Clinton, NC (LSD = 8.03) and the impact of soil amendment and time on the channel index at (C) CEFS, Goldsboro, NC (LSD = 15.13), and (D) HCRS, Clinton, NC (LSD = 10.04) Points in a column with the same letter not significantly different from one another $P < 0.05$).

amendments on nematode community dynamics in soils. Other researchers in Florida, California, and The Netherlands have observed that nematode community structure and trophic groups are affected by organic and synthetic soil fertility amendments. Bacterivorous nematodes increased after organic amendments were applied to soil, and populations decreased over time (Bouwman and Zwart, 1994; Bongers and Ferris, 1999; Ferris et al., 1996; McSorley and Gallaher, 1996; McSorley and Frederick, 1999). Rhabditid nematodes were also higher in soils with compost amendments in citrus agroecosystems in Florida, whereas plectid nematodes were not increased significantly (Porazinska et al., 1999). Bacterivorous nematode populations in our study were dominated by rhabdidid and cephalobid nematodes, which also increased after application of compost cotton-gin trash or swine manure.

In our research, fungivorous nematodes were lower consistently in soils amended with synthetic fertilizers than in soils with organic amendments. Further, high populations of bacteria were found in soils from our plots associated with the animal manures and composted cotton-gin trash (Bulluck and Ristaino, 2001), thus suggesting a bacteria-dominated decomposition food-web. This is further supported by the nematode faunal analyses (Fig. 5), and concurs with research elsewhere (Ferris et al., 2001). In a study of soils from the sustainable agriculture

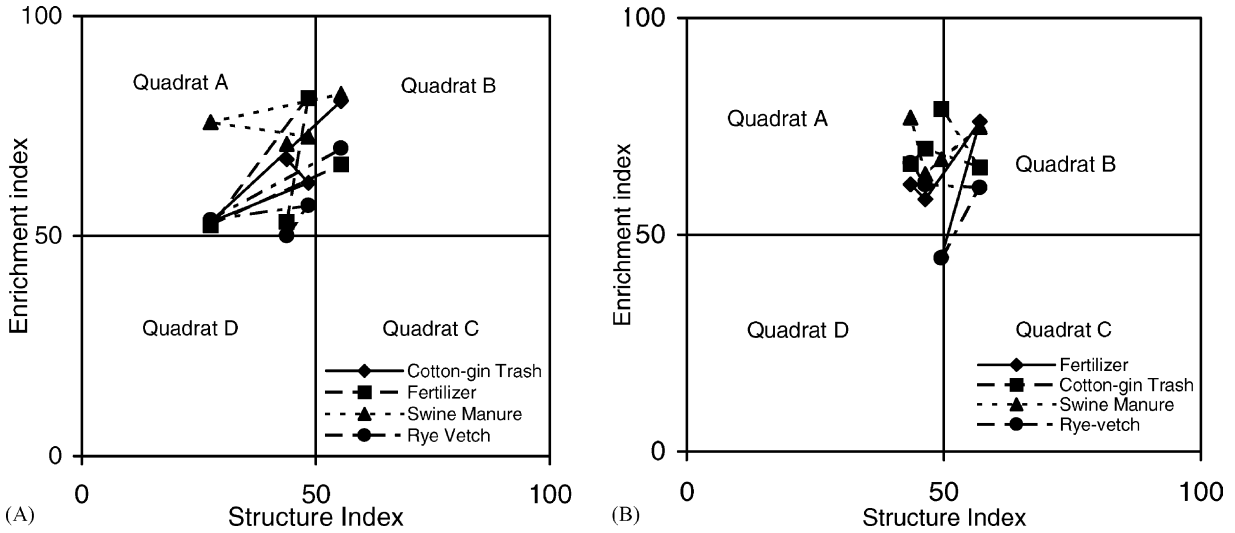

Fig. 5. Temporal changes in the soil food web indicated by nematode faunal analysis in plots receiving different organic or synthetic soil amendments. The weighted structure index is plotted against the enrichment index at (A) CEFS, Goldsboro, NC (B) HCRS, Clinton, NC.

farming Systems study in California, higher populations of fungivores were observed in conventional production systems than in organic systems, indicating a fungal-decomposer-dominated food-web (Ferris et al., 1996). Tillage and host crops varied between our study and the one in California.

In our study, no suppression of abundance of *M. incognita* or *Pratylenchus* species occurred with the addition of organic amendments. This is not a new finding but these results may be due to the short-term nature of our experiments and the susceptibility of the tomato crop to *M. incognita*. Others have observed that *M. incognita* and *Pratylenchus* spp. were consistently not affected by organic soil amendment in Florida soils receiving organic soil amendments (Mannion et al., 1994; McSorley and Gallaher, 1996; McSorley et al., 1998). Reduced populations of *M. incognita* have been observed when raw sewage sludge was added to soil, and the suppression was associated with ammonia released by the sewage sludge (Castagnone-Sereno and Kermarrec, 1991).

Plant-parasitic nematodes (especially *Meloidogyne* species) were relatively unaffected by soil amendment. Nevertheless, root-gall development caused by *M. incognita* was suppressed by composted cotton-gin trash and swine manure. This measurement is generally more precise than assessing numbers of *Meloidogyne* juveniles or eggs. Plant-parasitic nematodes are potentially more responsive to host plant than to soil amendment, especially in short-term experiments.

Other researchers have used green manures for plant-parasitic nematode suppression (Crow et al., 1996; El Titi and Ipach, 1989; Mojtahedi et al., 1993a; Mojtahedi et al., 1993b; MacGuidwin and Layne, 1995). Green manures, such as sudangrass can release cyanogenic compounds that can be effective against plant-parasitic nematodes (Viaene and Abawi, 1998). The rye-vetch green manure that was utilized in our work was ineffective in reducing populations of *M. incognita*, but *Pratylenchus* spp. were affected at HCRS. Ryegrass, sudangrass, and rapeseed have been associated with reduced populations of *Pratylenchus penetrans* on bean (Abawi and Widmer, 2000). Recently, chicken manure was identified as suppressive to *M. incognita* on cotton (Riegel and Noe, 2000) and to *P. penetrans* on bean (Abawi and Widmer, 2000).

Tillage did not affect the nematode community in our study. Tillage occurred in all plots in both experimental locations twice each spring prior to surface mulching, and cultivation continued throughout the season in tilled, bare-soil plots. In other research, the omnivorous nematodes in the family Dorylaimidae were decreased by cultivation (Bouwman and Zwart,

1994). Since tillage occurred at least twice in all of our plots during the growing season (at amendment incorporation and prior to surface mulching), it is unlikely that populations of these nematodes would be able to recover sufficiently to affect the maturity indices or Shannon's index. Dorylaimid nematodes comprised a relatively small percentage of the nematode communities that were examined in our study and may have been affected by the tillage that occurred. Also, the method of elutriation may have underestimated the number of omnivores and predators in the samples (Neher et al., 1995). In a long-term experiment, the combination of reduced tillage, manure, and a clover cover crop in an integrated farming system, suppressed populations of *Ditylenchus dipsaci* and *Heterodera avenae* on cereals (El Titi and Ipach, 1989).

All nematodes within a given community were utilized for calculation of the combined maturity index $\sum$MI, and shifts in total nematode populations from one trophic group to another were better reflected in this index. The combined maturity index was more sensitive to changes in trophic group than either the plant parasite index or the free-living maturity index, since only the combined maturity index reflected differences in nematode communities over the course of our study. The differences in nematode populations observed in our study had more to do with a shift in nematode populations from a range of 40–70% bacterivorous nematodes at planting, to 80% plant-parasites at harvest. The c–p values for the majority of bacterivore families identified at CEFS and HCRS were 1 and 2 for Rhabditidae and Cephalobidae, respectively. Most of the plant-parasitic nematodes present had c–p values of 3. The effect was to bring the combined MI from near two in some plots at the first sampling episode to near three by the end of the experiment in almost all plots.

Plant-parasitic nematode pressure was very high at CEFS in both years and at the HCRS in the second year of the experiment. These high numbers of mainly *M. incognita* affected all measurements of nematode community structure at both locations. Shannon's diversity index, and Pielou's richness index were both good indicators of this increase in plant-parasitic nematodes at both sites. These measurements may have been better estimates of ecosystem functioning than the maturity index in this case. The plant-parasitic maturity index (PPI) was one measurement used to examine differences in a study of annual crop fields, perennial fields, and pastures (Neher and Campbell, 1994). Lower PPIs were observed in annual fields than pasture or perennial fields. Our research was focused on changes in soil amendment within a field, whereas Neher and Campbell (1994) examined the impact of soil disturbance and different types of agricultural production systems on maturity indices in North Carolina. Neher and Campbell (1994) found tillage decreased both MIs and Shannon's index (H'). Tillage did not affect maturity indices in our study.

In another study, crop species may have influenced nematode community structure more than management practices (Neher, 1999). However, in that study different fields from either organic or conventional agricultural production systems were sampled, whereas we examined the effects of organic amendments in soils from the same fields that were cropped to tomato. Our data reflect the short-term changes in soil nematode communities in response to soil amendments and not differences associated with cropping systems.

It has been noted that high-resolution taxonomy of nematode communities requires time and expertise and contributes little information to overall ecosystem functioning (Parmelee et al., 1995). Recent research however, points to the importance of specific nematode genera within trophic groups to ecosystem processes such as nutrient cycling (Porazinska et al., 1999). The bacterivorous rhabditid and cephalobid nematodes responded quickly but ephemerally to additions of compost mulch. Other bacterivorous nematodes (*Plectus* spp. most notably) were more abundant in soils with mulch additions, whereas certain cephalobid nematodes (mainly *Acrobeles*, *Acrobeloides* and *Eucephalobus* species) were less abundant in soils with mulch added (Porazinska et al., 1999).The use of nematodes to identify below-ground ecosystem biodiversity has several advantages to using other organisms present in soil communities. Nematodes are relatively easy to remove from soil, and do not require culturing for identification. Nematodes are one of the few groups of organisms in the soil that are present at several levels of the soil food-web (Bongers and Bongers, 1998). All measures of nematode community structure and diversity utilized in our study provided information about below-ground processes in agroecosystems. The uses of below-ground ecosystem biodiversity indices

are especially appropriate for agroecosystems, since above-ground biodiversity is often limited by design, through the reduction of competitive weed species. By utilizing diversity indices, maturity and soil food web indices, useful information about the soil food web can be obtained. When these variables are combined with other soil quality parameters, belowground biodiversity can be better understood and managed. While considerable progress has been made (Barker and Koenning, 1998; Bouwman and Zwart, 1994; Ferris et al., 1996, Riegel and Noe, 2000), greater efforts are needed to identify soil amendments that will provide suppression of plant-parasitic nematodes while not reducing populations of bacterivorous and fungivorous nematodes important for nutrient cycling.

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