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Differential effects of raw and composted manure on nematode community, and its indicative value for soil microbial, physical and chemical properties

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Abstract

The impacts of two organic soil amendments on nematode abundance, community structure and soil characteristics were studied in field grown tomatoes. We hypothesized that as the raw (labile form) and composted (non-labile form) manures differ in their chemical composition and effect on microbial activity. Also they will have different effects on soil properties and directly and indirectly affect nematode community structure. Experiments were conducted during 2001–2002 in Wooster, Ohio on a silt loam soil. Treatments [raw or composted dairy cow manure in 2001 and beef calf manure in 2002, and an untreated control] were arranged in a randomized complete block design. Amendments were applied in the spring at a rate estimated to deliver 95–100 kg N ha^{-1}, and incorporated prior to planting. Soil samples were collected in the spring (before adding amendments) and autumn (after crop harvest) to determine nematode abundance, community structure and soil characteristics: Shannon–Weiner (H'), Simpson (λ), Pielou (J') and combined maturity indices were used to compare nematode community structure in amended and non-amended plots. Spring incorporation of both organic amendments increased the abundance of bacterial feeding, fungal feeding, omnivorous and predatory nematodes, but decreased plant parasitic nematode populations. Plots treated with raw manure had the lowest number of plant parasitic nematodes while increases in non-plant parasitic nematodes were similar in both treatments. Shannon diversity (H') and combined maturity ($\sum$MI) indices of soil nematodes were reduced in plots receiving raw but not composted manure. Application of raw manure increased total organic matter, microbial biomass-N, potentially mineralizable-N and C over composted manure in 2001, while both raw and composted manure increased particulate organic matter in both years. The effect of raw and composted manure on community indices was different in 2001 and 2002. We found a strong negative relationship ($r = -82, p < 0.0001$) between the abundance of non-plant parasitic and plant parasitic nematodes across all treatments and sampling times, thus supporting the utility of the ratio between non-plant parasitic and plant parasitic nematodes as a useful soil quality indicator.

Keywords: Organic amendment; Soil quality; Nematode community structure; Plant parasitic nematodes; Raw manure; Composted manure

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1. Introduction

Application of animal and plant byproducts, along with rotation and cover cropping, are the foundation of alternative crop management systems that aim to reduce or eliminate synthetic inputs (Mian and Rodriguez-Kabana, 1982; Abawi and Widmer, 2000; McSorley and Frederick, 1999). Organic amendments improve soil quality and may reduce losses from diseases and pests and environmental pollution associated with the use of chemical fertilizers and pesticides while increasing crop yields. Organic amendments have been shown to reduce soil bulk density and increase soil nitrogen and carbon supply (Doran, 1995; Drinkwater et al., 1995). Guidi et al. (1983) reported differential effects of various organic amendments on soil properties; however, all amendments increased nutrients and organic C. Widmer et al. (2002) noted that addition of compost with a C:N ratio above 30 resulted in N-immobilization, leading to a reduction of available nitrogen for plants due to the accelerated growth of microbes that compete for nitrogen.

Nematode abundance and structure of the soil nematode community are influenced by vegetation, soil properties, soil temperature, moisture, season and nutrient dynamics (Goralczyk, 1998; Boag et al., 1998). Soils managed under organic farming practices have been shown to have greater microbial abundance and activity, and higher numbers of bacterial feeding nematodes than those managed under conventional fanning practices (Gunpala and Scow, 1998). Numbers of fungal and bacterial feeding nematodes tend to increase in organic management systems (Freckman, 1988; Griffiths et al., 1994), presumably because fungal and bacterial populations that provide a food base increase after application of organic amendments (Bongers and Ferris, 1999; Ferris et al., 1999; McSorley and Frederick, 1999). Changes in genera composition of bacteriovores were noted in soil under organic and conventional management in California, although the numbers of bacteriovores and total nematodes showed few differences over-time (Ferris et al., 1996).

The rate of decomposition of organic amendments influences the supply of plant nutrients and plays a key role in structuring soil nematode communities. Nitrate and ammonical nitrogen accumulated during decomposition are toxic to plant parasitic nematodes (Mian and Rodriguez-Kabana, 1982). Rodriguez-Kabana et al. (1987) reported that the nematicidal activities of an amendment depended on its chemical-composition and the type of organisms that develop during ‘‘degradation. Also nematode communities may help’’ regulate decomposition and nutrient cycling (Ingham et al., 1985). Ingham et al. (1985) postulated that nematodes assist in organic matter, decomposition by grazing on soil microbes, in effect selecting for an-active community with a high rate of N mineralization. Therefore, it is not surprising that nematodes are increasingly used in soil food-web analysis (Ferris et al., 2001; Bongers and Ferris, 1999; Porazinska et al., 1999). Abundance, diversity, richness, evenness and maturity indices of nematodes are considered indicators of soil environment/ecosystem status and are commonly used for comparing ecosystems affected by human intervention (Freckman and Ettema, 1993; Yeates et al., 1999; Bongers, 1990; Ferris et al., 1996).

As organic amendments differ in physical and chemical composition (Bulluck et al., 2002a), it is reasonable to expect that their effects on soil properties and nematode communities will vary (Bulluck et al., 2002b). Therefore, the objectives of this study were to compare the effects of raw and composted manure on trophic abundance and community structure (indices) of soil nematodes, and how this relates to soil characteristics (including bulk density, mineral nitrogen, organic matter, particulate organic matter, microbial biomass-N, potentially mineralizable-N and C). We hypothesized that as raw and composted manure differ in their chemical compositions, they impart different effects on soil properties and nematode community.

2. Materials and methods

2.1. Treatments and experimental design

The field experiments were carried out at the Ohio Agricultural Research and Development Center (OARDC), in Wooster, Ohio in 2001 and 2002. The treatments [raw and composted dairy cow manure (2001), raw and composted-beef calf manure (2002) and a non-amended control] were arranged in a randomized complete, block design with; four replications. In Spring 2001 and 2002, a total of 12 plots (112 m^2) were established in 1338 m^2 blocks, on soil cropped in 2000 with Berseem clover (*Trifolium alexandrinum* L.) and in 2002 with red clover (*Trifolium pratense* L.). Previous to 2000, the area used for the study had been cropped with a maize (*Zea mays*)–soybean (*Glycine max*) rotation with standard fertilization and pest management. Tomato (*Lycopersicon esculentum* L. ‘Peto 696’) seedlings produced in Paygro organic potting mix # 423 (35% composted pine bark, 50% Canadian sphagnum peat, 15% perlite) in a greenhouse. They were transplanted to field plots 7 weeks after sowing in 2001 and 8 weeks after sowing in 2002. Test areas consisted of 16, 30-m beds on 1.5 m centers, with each bed containing two rows of plants. In-row spacing was 40.6 cm and between-row spacing was 45.7 cm. Soil amendments were applied across the plots in spring at a rate estimated to deliver 95–100 kg N ha^{-1} and rightly incorporated prior to planting tomatoes. Plots were irrigated using a sprinkler system in 2001 and a drip system in 2002. The soil was a silt loam with pH 5.8 and 6.5 in 2001 and 2002, respectively. The chemical compositions of raw and composted manure were analyzed following standard procedures (Whitney, 1998) (Table 1). Plant available-N contents in manure were estimated from inorganic and organic forms of nitrogen in the raw and composted manures according to the formula: PAN = [Org-N] × A + [NH_4^+-N] × B + [NO_3^--N], where Org-N is the concentration of organic-bound N in the amendments as calculated by = [TKN − NH_4^+-N − NO_3^--N]; TKN is the total Kjeldahl nitrogen concentration; NH_4^+-N is the ammonium nitrogen concentration; NO_3^--N is the nitrate nitrogen concentration; A is the fraction of Org-N expected to mineralize or became plant available in the year of application, generally estimated to be approximately 0.2 for composted and 0.35-for raw manure; B is the fraction of NH_4^+-N expected to be available in the year of application, generally expected to be 1.0 for composted and 0.85 for raw manures (Evanylo, 1994).

2.2. Soil sampling

Soil samples were collected in spring (before adding organic matter) and autumn (after crop harvesting). Three cores (7.5 cm diameter and 15 cm deep) of soil were collected randomly from each plot using a soil auger. Collected soil samples were mixed thoroughly to form a composite sample and reduce the variance associated with aggregated spatial patterns of nematodes in soil (Barker and Campbell, 1981). Large plant parts or stones were separated from soil samples by passing them through a soil sieve (6 mm mesh). All soil samples were stored in the dark overnight at 5 °C and existing field moisture levels were maintained to minimize changes in nematode populations and biochemical reactions (Barker et al., 1969).

2.3. Nematodes extraction, identification and counting

Nematodes were extracted from 10 g soil subsamples taken from each composite soil sample using

Table 1
Nutrient status of raw manure and composted manure applied to tomato plots in Spring 2001 and 2002

	2001		2002	
	Raw manure[a]	Composted manure[a]	Raw manure[b]	Composted manure[b]
pH	8.5	8.0	7.3	8.1
Solids (kg/ha)	9227.8	5625.7	5863.5	6637.9
Volatile solids (kg/ha)	13396.2	9618.3	15131.4	11272.3
Released N from amendments (kg/ha)				
Total-N	238.6	370.9	212.3	432.0
NH_4^+-N	34.46	28.72	41.63	8.58
NO_3^--N	0.02	1.29	0.01	2.88
Available nutrients from amendments (kg/ha)				
Total-C	6655.9	5247.8	7124.4	6235.0
P	44.70	56.02	31.30	53.69
K	227.3	186.0	127.7	343.6
Ca	123.0	479.7	124.5	146.2
Mg	37.08	63.32	32.38	343.56
S	31.76	35.52	32.97	39.08
B	0.13	0.15	0.19	0.38
Cu	2.94	0.64	1.91	0.24
Fe	11.66	25.87	13.44	4.64
Mn	1.75	4.56	1.57	1.40
Zn	1.40	1.64	0.90	1.12
Total PAN[c] (kg/ha)	100	98	95	97

[a] Dairy manure.
[b] Beef calf manure.
[c] Plant available nitrogen calculated following Bulluckm et al. (2002b).

the Bearmann funnel technique (Flegg and Hooper, 1970). Nematodes were collected at 24 h intervals for 72 h, heat-killed, and fixed with triethanolamine formaldehyde (TAF) solution (Shepherd, 1970). Specimens were identified to the genus level using an inverted compound microscope at 40× magnification. Diagnostic keys by Goodey (1963), Siddiqi (1986), Jairajpuri and Ahmad (1992) were used for identification. Numbers of nematodes were not corrected for extraction efficiency. Nematode genera were assigned to a trophic group (plant parasitic, fungal feeders, bacterial feeders, omnivpres and predatory) according to Yeates et al. (1993). Nematode genera were also assigned a colonizer-persister value (*c–p* value) according to Bongers (1990).

2.4. Soil analysis

Soil bulk density, organic matter, particulate organic matter (0.05–2 mm), mineral associated organic matter (<0.05 mm), mineral-N (NH_4^+-N, NO_3^-N), potentially mineralizable-N and C were analyzed at the Field Crop Ecology Laboratory, OARDC, Wooster, using standard methods (Sims et al., 1995). Microbial biomass-N was determined using modified chloroform fumigation methods (Brookes et al., 1985).

2.5. Statistical analysis

Nematode abundance was based on trophic groups (Yeates et al., 1993), community richness, nematode diversity, community evenness and maturity indices. *Filenchus* was placed in plant parasitic nematodes due to the morphology of mouth parts, although their feeding habits are uncertain (Somasekhar et al., 2002). The root lesion nematode, *Pratylenchus crenatus* was counted separately as it was most abundant and has been reported to cause significant yield losses in vegetable crops in North America (Brodie, 1984). Community indices of soil nematodes were calculated as follows:

Richness: (i) *Margalef* = $(G - 1)/\ln(n)$, where G is the total number of genera and n is the total number of individuals in the community and (ii) *Menhinick* = $G/\sqrt{n}$ (Menhinick, 1964).

Diversity: (i) *Shannon–Weiner index* $(H') = -\sum P_i(\ln P_i)$, where P_i is the proportion of genera n_i in the total nematode community n, (ii) *Hill's N1 index* = $e^{H'}$, (iii) *Simpson index* $(\lambda) = \sum n_i(n_i - 1)/n(n - 1)$, where n_i is the number of nematodes in genera i and n is the total number of individuals in the community and (iii) *Hill's N2 index* = $1/(\lambda)$ (Heip et al., 1988; Ludwig and Reynolds, 1988).

Evenness: (i) *Pielou index* $(J') = H'/\ln(G)$, where G is the number of genera in the community, (ii) *modified Hill's ratio* = $(1/\lambda) - 1/e^{H'} - 1$ (Pielou, 1977).

Maturity index = $(\sum v_i f_i)/n$, where v_i is the *c–p* value assigned to genus i, f_i the frequency of genus i and n is the total number of the nematodes in the sample (Bongers, 1990).

Ratio of plant parasitic and non-plant parasitic nematodes.

The familiar evenness index is J' of Pielou, which expresses H' relative to the maximum value that H' can obtain when all of the species in the sample are perfectly uniform with one individual per species. Another evenness index, *modified Hill's ratio*, approaches zero as a single species becomes more and more dominant in a community. The maturity index is a measure based on ecological characteristics of nematode genera. In this index, nematode genera are classified on a colonizer–persister (*c–p*) scale of 1–5, with colonizers (short life cycle, high reproduction rates, tolerance to disturbance) = 1 and persisters (long life cycle, low colonization ability, few offspring, sensitive to disturbance) = 5. Non-plant parasitic nematode genera are assigned *c–p* values from 1 to 5 while plant parasitics are assigned *c–p* values 2–5, because there are no plant parasitic nematodes assigned *c–p* value of 1 (Bongers, 1990). Classification of nematode genera using *c–p* values implies that nematode genera under the same *c–p* value are adapted similarly to specific environmental conditions and food sources through anatomical and physiological commonalities (Ferris et al., 2001). Genera within the same *c–p* value are also similar, in their responses to disturbance (Bongers, 1999; Bongers and Ferris, 1999).

Data were analyzed using SAS software (PROC GLM, SAS version 8.2, SAS Institute, Garry, NC). Means were separated using Fisher's LSD test arid linear contrasts. As soil management was different in 2001 and 2002, we analyzed data separately for each year. Pearson correlations (PROC CORR) were performed to quantify relationships between trophic abundance, community indices, soil properties and microbial biomass-N in plots amended with raw and composted manure.

3. Results

Twenty seven genera were identified, 2 fungal feeding (*Aphelenchoides* and *Aphelenchus*); 11 bacterial feeding (*Rhabditis, Cuticularia, Cephalobus, Acrobeloides, Acrobeles, Plectus, Wilsonema, Mononchoides, Teratocephalus, Monohystera* and *Turbatrix*); 1 predatory {*Mononchus*)}; 7 plant parasitic (*Pratylenchus crenatus, Paratylenchus, Helicotylenchus, Hoplolaimus, Tylenchus, Filenchus, Xiphenama*). Among them the most abundant genera were *Aphelenchoides, Aphelenchus, Rhabditis, Cephalobus, Acrobeloides, Monohystera, Mononchus, Pratylenchus crenatus, Paratylenchus, Helicotylenchus, Tylenchus* and *Filenchus*.

3.1. Trophic abundance

Significant treatment effects on the abundance of nematodes in all trophic groups were observed only in soils sampled in autumn (Fig. 1). Raw manure reduced the abundance of plant parasitic nematodes in 2001, while both manures produced the same result in 2002 ($p < 0.05$). Both amendments significantly increased the abundance of bacterial feeding and omnivorous nematodes relative to non-amended control plots in both

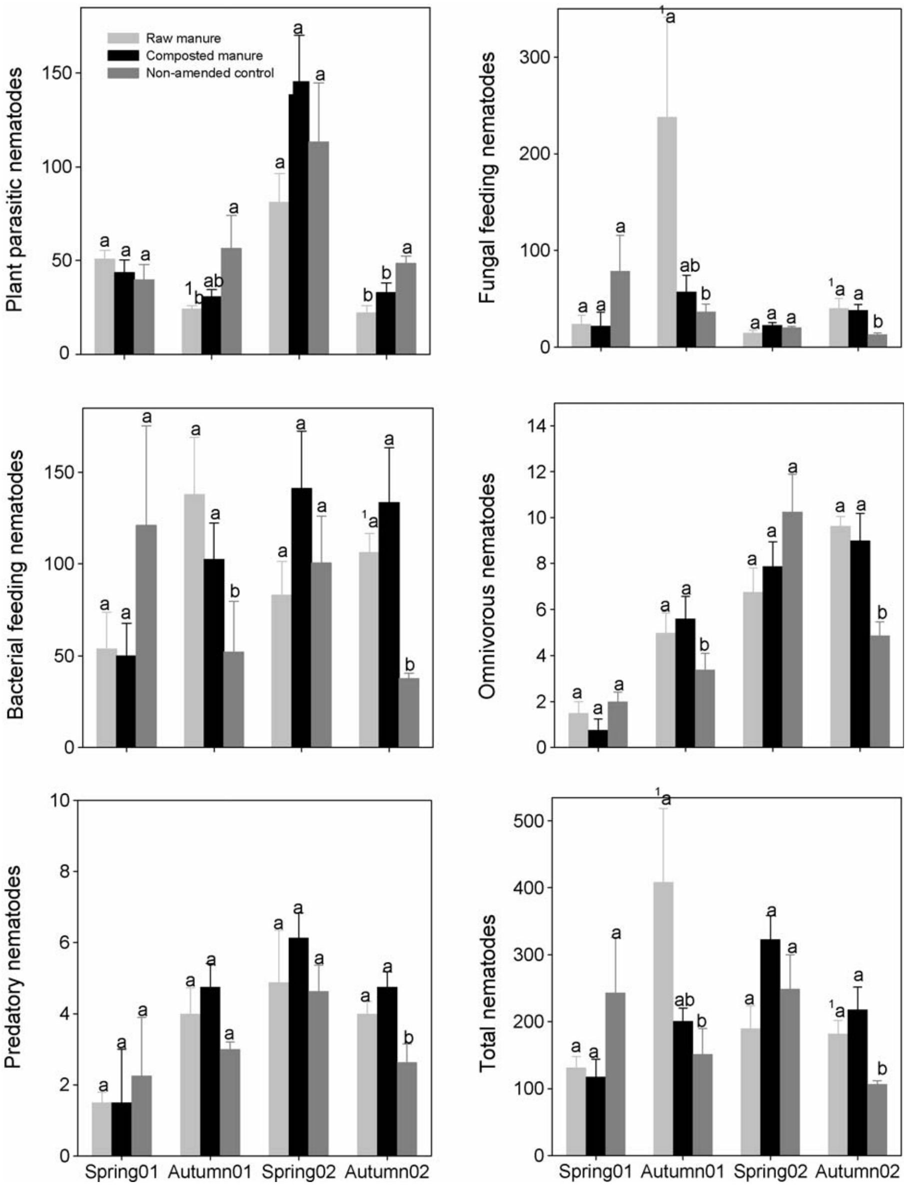

Fig. 1. Mean trophic abundance of soil nematodes in 10 g soil. Values shown are the mean of four replications, ±standard error of mean. Treatments within a group with the same letter are not significantly different ($p < 0.05$) by Fishers's LSD test. 'Data analysis was performed using log 10× transformed values.

years. The number of fungal feeding nematodes increased in soils amended with raw manure in 2001 and 2002, and in soils amended with composted manure in 2002 ($p < 0.05$). The abundance of predatory nematodes (*Mononchus*) was higher in both raw and composted manure treatments than the control in Autumn 2002 but not in the Autumn of 2001. Total nematode abundance was higher in raw manure-amended plots than in non-amended control plots in Autumn 2001 and 2002, while abundance in plots treated with composted manure was significantly higher than in plots receiving-no amendment in Autumn 2002 only.

3.2. Community structure

Soil nematode community richness, diversity, evenness and maturity indices were affected by amendments for the autumn sampling periods. Raw manure reduced *Menhinick* but not *Margalf* index values of total nematodes in both years (Table 2). The Shannon diversity index (H') of total nematodes was lower in plots receiving raw manure relative to non-amended control plots in both years ($p < 0.05$), but not in plots receiving composted manure. Similar trends were observed for Hill's N1 and N2, and Simpson (reciprocal of N2) diversity indices. Community evenness indices

Table 2
Effect of organic amendments on community richness, evenness and diversity indices of total nematodes in soil

	Spring 2001	Autumn 2001	Spring 2002	Autumn 2002
Species richness				
(i) Margalef index				
Raw manure	2.98a	2.92a	2.84a	2.79b
Composted manure	2.77a	3.22a	2.97a	3.08a
Non-amended control	2.76a	3.17a	2.94a	3.00ab
(ii) Menhinick index				
Raw manure	1.36a	1.04b	1.22a	1.09b
Composted manure	1.35a	1.29ab	1.04a	1.17ab
Non-amended control	1.13a	1.44a	1.11a	1.34a
Diversity index				
(i) Shannon diversity (H')				
Raw manure	2.13a	1.52b	2.13a	2.15b
Composted manure	2.24a	2.09a	2.11a	2.28ab
Non-amended control	1.94a	2.31a	2.16a	2.37a
(ii) Hill's N1				
Raw manure	6.68a	4.80b	8.58a	8.76b
Composted manure	7.76a	8.32a	8.44a	9.79ab
Non-amended control	6.72a	10.16a	8.77a	10.76a
(iii) Simpson index (λ)				
Raw manure	0.18a	0.38a	0.18a	0.18a
Composted manure	0.13a	0.21b	0.17a	0.15ab
Non-amended control	0.18a	0.13b	0.16a	0.11b
(iv) Hill's N2				
Raw manure	3.58a	2.87b	6.25a	6.15b
Composted manure	4.31a	5.59ab	6.33a	6.88b
Non-amended control	3.95a	8.29a	6.30a	8.99a
Species evenness				
(i) Pielou's J'				
Raw manure	0.78a	0.53b	0.77a	0.77b
Composted manure	0.85a	0.72a	0.74a	0.79ab
Non-amended control	0.71a	0.82a	0.77a	0.86a
(ii) Modified Hill's ratio				
Raw manure	0.70a	1.83b	0.67a	0.65b
Composted manure	0.79a	1.92ab	0.70a	0.66b
Non-amended control	0.79a	2.14a	0.68a	0.81a

Means within the same column and index followed by the same letters (a and b) are not significantly different according to Fisher's LSD test ($p < 0.05$).

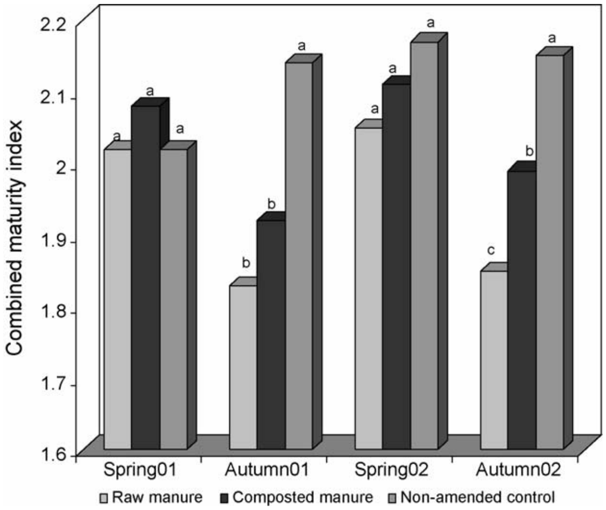

Fig. 2. The combined maturity index before and/or after adding raw or composted manure in 2001 and 2002. Values shown are the mean of four replications. Treatments within a group with the same letter are not significantly different ($p < 0.05$) by Fisher's LSD test.

(Pielou's J' and *modified Hill's ratio*) based on total nematodes were also lower in plots amended with raw manure than in non-amended control plots. The combined maturity index ($\sum$MI) was significantly ($p < 0.05$) reduced in treatment relative to control plots in both years, with raw manure leading a significantly greater reduction than the composted manure in 2002 ($p < 0.05$) (Fig. 2). The ratio of plant parasitic to non-plant parasitic nematodes was significantly reduced in both treatments compared to the control in both years (Fig. 3).

3.3. Relationship between plant parasitic and non-plant parasitic nematodes

Across all sampling times, the abundance of *Pratylenchus crenatus* was negatively correlated with the proportion of bacterial feeding ($p = 0.012$) and total non-plant parasitic ($p = 0.0001$) nematodes (Fig. 4). The proportions of bacterial feeding ($p = 0.0002$) and total non-plant parasitic ($p = 0.0001$) nematodes were also negatively correlated with the abundance of total plant parasitic nematodes.

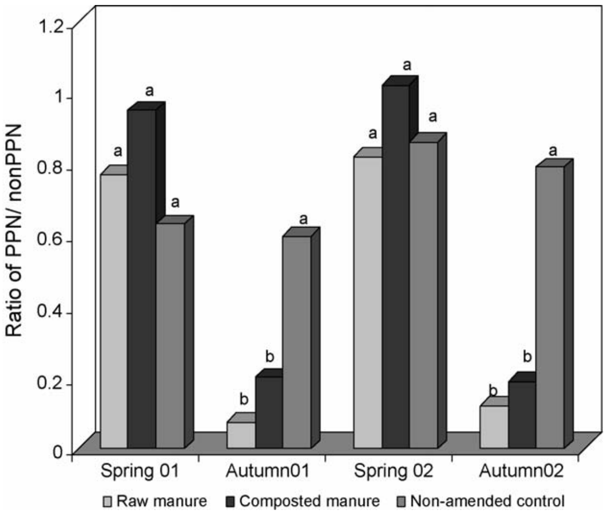

Fig. 3. Ratio of plant parasitic (PPN) and non-plant parasitic nematodes before and/or after adding raw or composted manure in 2001 and 2002. Values shown are the mean of four replications. Treatments within a group with the same letter are not significantly different ($p < 0.05$) by Fisher's LSD test.

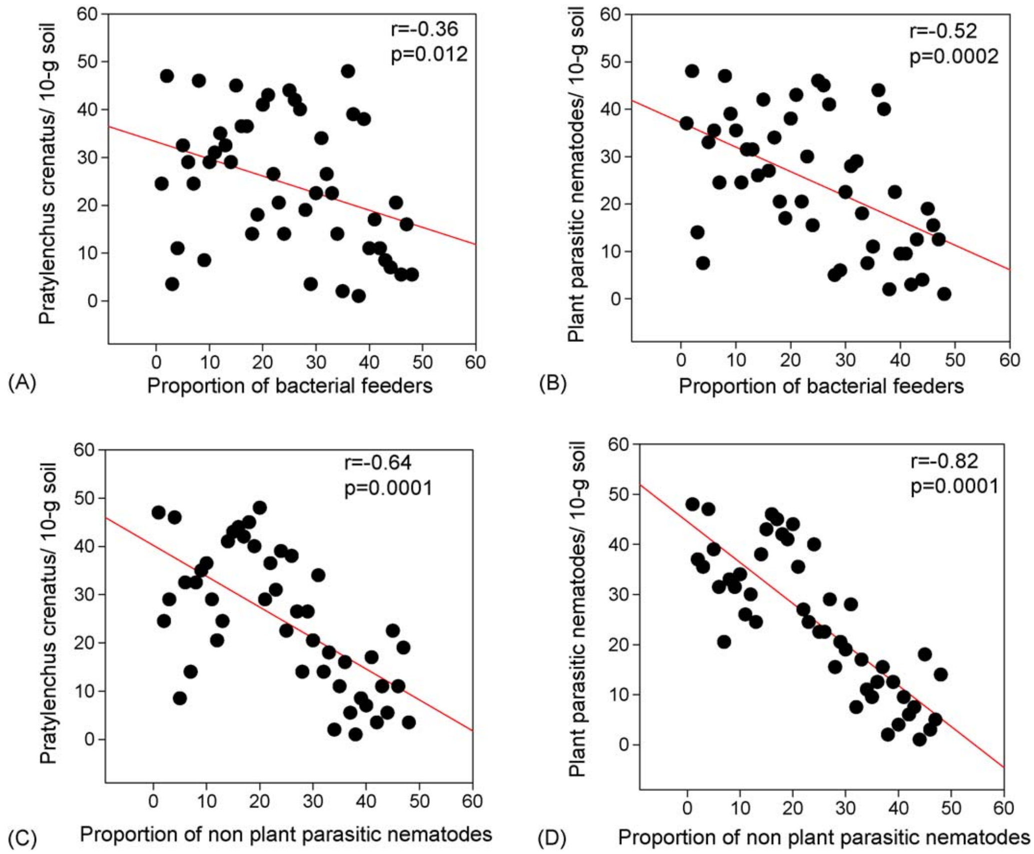

Fig. 4. Relationship between the proportion of bacterial feeding nematodes and *Pratylenchus crenatus* (A), proportion of bacterial feeding nematodes and total plant parasitic nematodes (B), proportion of non-plant parasitic nematodes and *P. crenatus* (C) and proportion of total non plant parasitic nematodes and total plant parasitic nematodes (D).

3.4. Soil properties and microbial biomass-N

Amendments did not reduce ($p < 0.05$) soil bulk density in Autumn 2001 or 2002. Organic matter content in soil was significantly higher in plots receiving raw manure compared to plots receiving composted manure or no amendment in Autumn 2001 ($p = 0.003$), but not in Autumn 2002 (Table 3). Both raw and composted manure increased particulate organic matter in Autumn 2001 ($p = 0.004$) and Autumn 2002 ($p = 0.03$). Mineral associated organic matter increased ($p < 0.05$) in plots amended with raw manure in Autumn 2001 only.

Neither raw nor composted manure had any consistent effect on soil mineral-N (NH_4^+ and NO_3^-) (Table 4). Raw manure increased microbial biomass-N ($p = 0.003$) and potentially mineralizable-N ($p = 0.05$) and C ($p = 0.02$) relative to the non-amended control and composted manure in Autumn 2001, but not in Autumn 2002. There were no significant differences in soil properties or microbial biomass-N in the plots before adding organic amendments in Spring 2001 and 2002.

4. Discussion

Changes in the occurrence and abundance of different trophic groups of nematodes are often associated with changes in crop host and soil management practices (Ettema and Bongers, 1993; Freckman and Ettema, 1993), and may reflect changes in the soil food web structure. The abundance of plant parasitic nematodes was higher in Spring 2002 than in Spring 2001, perhaps because of the use of red clover as a rotational crop in 2001. Red clover is a good host of *Pratylenchus, Paratylenchus, Helicdtylenchus* and *Xiphinefna* (Freekman and Chapman, 1972), which were dominant plant parasitic nematodes in our experimental plots. The effect of host plant on the structuring of nematode communities have been documented (Neher, 1999), and can be direct (quantity and quality of food resource) or indirect (changes in soil

Table 3
Effect of organic amendments on soil bulk density and various organic matter fractions

	Bulk density	% Organic matter (OM)	% Particulate organic matter (0.05–2 mm)	% Mineral associated OM (0.05 mm)
Spring 2001 (before adding organic amendments)				
Raw manure	1.53a	2.18a	0.51a	1.47a
Composted manure	1.51a	2.13a	0.48a	1.55a
Non-amended control	1.52a	2.06a	0.48a	1.42a
Autumn 2001 (after adding organic amendments)				
Raw manure	1.43a	2.24a	0.57a	1.66a
Composted manure	1.45a	2.07b	0.52a	1.56ab
Non-amended control	1.50a	1.97b	0.40b	1.53b
Spring 2002 (before adding organic amendments)				
Raw manure	1.40a	2.15a	0.53a	1.59a
Composted manure	1.41a	2.19a	0.55a	1.62a
Non-amended control	1.41a	2.19a	0.55a	1.61a
Autumn 2002 (after adding organic amendments)				
Raw manure	1.32a	2.68a	0.57a[a]	2.09a
Composted manure	1.31a	2.67a	0.59a	2.06a
Non-amended control	1.38a	2.65a	0.53b	2.10a

Means within the same column and sampling period followed by the same letters (a and b) are not significantly different according to Fisher's LSD test ($p \leq 0.07$).
[a] Data analysis was performed by following log x transformed values.

properties). Differences in the effects of organic amendments in 2001 and 2002 may also be due to the different irrigation systems used and dry weather in 2002. The drip irrigation system used in 2002 delivered moisture to a narrower band near plant roots than the sprinkler system used in 2001. Soil outside this band likely had reduced microbial activity due to the persistent drought conditions.

The accumulation of certain nitrogenous compounds (toxic for nematodes) produced during organic matter

Table 4
Effect of organic amendments on mineral-N, microbial biomass, potentially mineralizable-N and C ($\mu g\ g^{-1}$)

	Mineral-N		Microbial biomass-N	Potentially mineralizable-N and C/day	
	NH_4^+-N	NO_3^--N		Total N	Total-C
Spring 2001 (before adding organic amendments)					
Raw manure	2.34a	4.24a	42.14a	0.76a	12.46a
Composted manure	2.78a	5.45a	35.29a	1.00a	14.65a
Non-amended control	2.20a	3.65a	36.30a	0.82a	22.55a
Autumn 2001 (after adding organic amendments)					
Raw manure	1.19a	10.69a	51.57a	0.88a	9.44a
Composted manure	1.11a	11.46a	40.38b	0.58b	6.33b
Non-amended control	1.34a	9.63a	38.18b	0.58b	4.72b
Spring 2002 (before adding organic amendments)					
Raw manure	1.36a	7.04a	44.17a	0.89a	9.13a
Composted manure	1.36a	8.98a	42.54a	0.89a	17.28a
Non-amended control	1.54a	8.22a	45.23a	0.91a	21.20a
Autumn 2002 (after adding organic amendments)					
Raw manure	0.59a	10.90ab	55.09a	0.68a	10.40a
Composted manure	0.69a	9.04b	45.24a	0.67a	11.78a
Non-amended control	0.82a	16.66a	48.16a	0.64a	10.35a

Means within the same column and sampling period followed by the same letters (a and b) are not significantly different according to Fisher's LSD test ($p \leq 0.05$).

decomposition is often cited as a possible mechanism for reducing the levels of plant parasitic nematodes (Rodriguez-Kabana et al., 1981; Rodriguez-Kabana, 1986). Nitrous oxide (N_2O-N) and methane (CH_4) emissions from grassland soil following dairy cow manure application have been reported (Chadwick et al., 2000). A laboratory investigation to identify the nitrogenous compounds that could cause poor growth of corn (*Z. mays* L.) following application of liquid beef manure demonstrated that conditions potentially toxic to plants were generated initially by free NH_3 (due to high pH and high concentrations of water-extractable and exchangeable NH_4-N), and subsequently by accumulation of NO_2-N (Schmitt et al., 1992). The raw manure amendment consistently reduced plant parasitic nematode populations compared to the non-amended controls in our experiment, suggesting that the raw manure may have produced nematicidal substances (CH_4, NH_3, N_2O, NO_2) during decomposition.

We observed a strong negative correlation between non-plant parasitic and plant parasitic nematodes. Both raw and composted manure increased the numbers of non-plant parasitic nematodes and lowered the ratio of plant parasitic to non-plant parasitic nematodes, possibly due to antagonistic effects of microbial communities. Hominick (1999) reported that progressive accumulation of organic matter in the soil promotes the emergence of antagonistic organisms that maintain the populations of plant parasitic nematodes below damaging levels. Organic matter increases food sources for microbes and enhances microbial activities that reduce plant parasitic nematodes through competition, antagonism or by generally creating unfavorable conditions (De Guiran et al., 1980).

Overall, application of raw and composted manure led to increases in fungal feeding and bacterial feeding nematode populations. Likewise, amendments of raw swine manure have been shown to double the abundance of bacterial feeding and fungal feeding nematodes (Bulluck et al., 2002a). Quick responses of non-plant parasitic nematodes, including fungal feeders and bacterial feeders, to organic amendments have been attributed to increases in food availability (Ferris et al., 1999, 2001; Wardle et al., 1995; Griffiths et al., 1994).

Based on total nematodes, significantly lower diversity indices in raw manure-amended plots were associated with increases in bacterial feeding nematode populations, in which rhabditid and cephalobid nematodes were dominant. Therefore, our results suggest that a bacterial-decomposer pathway dominated. Bulluck et al. (2002a) reported a decrease in the Shannon diversity index due to an increase in rhabditid nematodes following application of raw swine manure. The lower *Menhinick* richness index in our amended plots reflects an increase in the number of individuals within a genus but not the number of genera. Evenness indices (Pielou's *J* or *modified Hill's ratio*) were reduced due to the increase in the rhabditids group. In our study, the lower combined maturity index ($\sum$MI) in raw and composted manure treatments was associated with *r*-selected (*c–p* 1) nematode dominance. *r*-Selected nematodes with lower *c–p* values, including rhabditid group, have high rates of reproduction and respond rapidly to bacterial blooms (Bongers and Ferris, 1999; Bongers, 1999), resulting in a decreased maturity index ($\sum$MI) (Porazinska et al., 1999). Increases in microbial biomass-N are consistent with increases in the total microbial population in the raw manure treatment.

Nematodes are reliable bioindicators of soil ecosystem function and can be used to estimate community indices (Freckman and Ettema, 1993; Yeates et al., 1999; Ferris et al., 1999, 2001). While the effects of raw and composted manure on most community indices were statistically similar in this study, there was a consistent trend towards a greater impact of the raw compared to the composted manure. The differences we observed in community indices may be a manifestation of variations in soil ecosystem functions (e. g. decomposition and mineralization) following from differential impacts of amendments on soil properties and microbial communities, including nematodes. In a practical sense, while composted manure is often recommended as a soil amendment for conventional and organic systems, raw manure may be preferable in some cases. In fields in which plant parasitic nematodes are prevalent, application of raw manure may be more effective than composted manure in reducing plant parasitic nematodes while increasing beneficial species, provided appropriate time is available before crop planting.

As differential impacts of raw (labile) and composted (non-labile) manures nematode communities and soil properties were observed in a relatively short time, possible long term effects of these two amendments need to be investigated. Over time, these amendments-may affect nematode colonization and facilitate a cascade of changes differently, thereby interacting with soil quality, plant health and soil ecosystem function.

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