Pedobiologia **43**, 430–438 (1999)
Urban & Fischer Verlag
http://www.urbanfischer.de/journals/pedo

Pedo biologia

Nematode communities in soils of four farm cropping management systems

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Accepted: 9. July 1999

Summary. Nematode community composition was compared for four farm cropping management systems near Ithaca, Nebraska, USA. Management systems differed in their source of nutrients and pest management, and were designated as manure only (O), mineral fertilizer only (F), mineral fertilizer plus herbicides (HF), and mineral fertilizer, herbicides plus insecticides (HFI). All farming systems were cultivated annually and planted to annual crops either in rotation (O, F, HF systems) or continuous corn (HFI system). Eleven nematode community (plant-parasites and free-living) and four microbial biomass indices were measured in 1993, 18 years after establishment of management practices. Numbers of bacterivores and plant-parasites and maturity index (PPI and PPI:MI) values were greater, and MI1-5 values smaller, with manure than mineral fertilizer applications. MI2-5 values decreased with additions of herbicides and/or insecticides but were not sensitive to source of nutrients. Total fungal biomass and active bacterial biomass were associated positively with application of insecticides. Numbers of *Pratylenchus* increased and *Cephalobus* decreased with applications of manure compared to mineral fertilizers. Numbers of *Helicotylenchus* decreased with additions of mineral fertilizer, herbicides and insecticides but *Monhystera* and *Mylonchulus* abundance increased with insecticide applications. This study demonstrates differential effects of pesticides and nutrient source on nematode community composition.

Key words: Agroecosystems, indicator, Maturity Index, nematodes, Shannon-Weaver, trophic diversity

Introduction

Soil management practices are usually a combination of disturbance types. For example, management practices described as "organic", "integrated" or "conventional" imply a mixture of management practices. It is a major challenge to separate effects of physical and chemical disturbances which are often confounded in these practices (Fiscus 1997). Some nematode genera are more sensitive to either cultivation or chemical disturbance while others are sensitive to both types of disturbance combined. Sometimes, cultivation and nutrient enrichment alter a nematode population responds to cultivation and nutrient en dance. Increased understanding of the s practices, individually and in combinat bration and interpretation of nematode vironmental monitoring programs (Neh Fiscus 1997).

Many short-term studies that descri practices on nematode community stru fies nematode community composition agement systems. Specifically, effects fertilization alone, combined with herb We predicted that management practi tilizer would increase microbial bioma nematodes, and reduce numbers of pl insecticides were predicted to reduce n shift nematode communities to an earl

Materials and Methods

A long-term agricultural experiment was e Research and Development Center near It burg silty clay loam soil. The objectives o of four eastern Nebraska farming systems organic methods with crop rotations to co Sahs & Lesoing 1985; Lesoing 1992). Tre mineral fertilizer only (F), mineral fertiliz insecticides (HFI). All farming systems v rotation (O, F, HF systems) or continuous (corn-soybeans-corn-oats/clover) was rep hectare and arranged in a randomized co sions for each system followed best mana area.

Table 1. Characteristics of the four crop son study

	C
Crop sequence,[a] 1975–1992	C-B-C
Crops grown, 1993	C,B,S
Fertilizer	Manure o
Herbicides	N
Insecticides	N

[a] C=corn, *Zea mays* L.; B=soybeans, clover, *Trifolium pratense* L.; S=sorg
[b] In 1993, 7 metric tons compost (dry
[c] No fertilizer applied in 1993; other y
[d] corn and sorghum fertilized at 78 kg
[e] 1993 herbicides: corn – Arena (15% 0.9 l/ha); sorghum – Dual (86.4% a.i. l/ha); soybeans – Dual (86.4% a.i., g/ha); oat/clover – Butyrac 200 (25.9
[f] In 1993, Counter systemic insecticid (15% a.i.); sorghum seed treated wit

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0031-4056/99/43/05-430 $12.00/0

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enrichment alter a nematode population in an additive manner, and other times a population responds to cultivation and nutrient enrichment oppositely giving no net change in abundance. Increased understanding of the specific effects of cultivation and chemical application practices, individually and in combination, on nematode communities is important for calibration and interpretation of nematode community indices for use in regional or national environmental monitoring programs (Neher & Campbell 1994, 1996; Neher et al. 1995, 1998; Fiscus 1997).

Many short-term studies that describe effects of individual components of management practices on nematode community structure produce contradictory results. This study quantifies nematode community composition in four, long-term (18 consecutive years) farm management systems. Specifically, effects of organic manure are compared with those of mineral fertilization alone, combined with herbicides, or combined with herbicides and insecticides. We predicted that management practices that used organic manure in place of mineral fertilizer would increase microbial biomass, organic matter content, numbers of bacterivorous nematodes, and reduce numbers of plant-parasitic nematodes. Furthermore, herbicides and insecticides were predicted to reduce numbers of free-living nematodes, trophic diversity, and shift nematode communities to an earlier successional state.

Materials and Methods

A long-term agricultural experiment was established in 1975 at the University of Nebraska Agricultural Research and Development Center near Ithaca, Nebraska (Lat. 41:10:00, Long. 96:25:00) on a Sharpsburg silty clay loam soil. The objectives of the original project were to compare the overall performance of four eastern Nebraska farming systems representing different levels of chemical inputs ranging from organic methods with crop rotations to continuous corn with mineral fertilizers and pesticides (Table 1, Sahs & Lesoing 1985; Lesoing 1992). Treatments were assigned as follows: manure only (O=organic), mineral fertilizer only (F), mineral fertilizer plus herbicides (HF), and mineral fertilizer, herbicides plus insecticides (HFI). All farming systems were cultivated annually and planted to annual crops either in rotation (O, F, HF systems) or continuous corn (HFI system). Each stage of the crop rotation sequence (corn-soybeans-corn-oats/clover) was represented each year since 1975. Experimental units were 0.047 hectare and arranged in a randomized complete block design with four replications. Management decisions for each system followed best management practices for comparable farming systems in the local area.

Table 1. Characteristics of the four crop management systems in the long-term (1975–1993) comparison study

	Management System			
	O	F	HF	HFI
Crop sequence,[a] 1975–1992	C-B-C-O/Cl	C-B-C-O/Cl	C-B-C-O/Cl	C-C-C-C
Crops grown, 1993	C,B,S,O/Cl	C,B,S,O/Cl	C,B,S,O/Cl	C,B,S
Fertilizer	Manure or compost[b]	Mineral[c]	Mineral[d]	Mineral[e]
Herbicides	No	No	Yes[e]	Yes[e]
Insecticides	No	No	No	Yes[f]

[a] C=corn, *Zea mays* L.; B=soybeans, *Glycine max* (L.) Merr.; O/Cl=oats, *Avena sativa* L., and red clover, *Trifolium pratense* L.; S=sorghum, *Sorghum bicolor* (L.) Moench
[b] In 1993, 7 metric tons compost (dry weight) applied per ha (62 kg N/ha)
[c] No fertilizer applied in 1993; other years liked
[d] corn and sorghum fertilized at 78 kg N/ha in 1993
[e] 1993 herbicides: corn – Arena (15% a.i., 4.7 l/ha), Bladex 4L (43% a.i., 4.7 l/ha), Buctril (56% a.i., 0.9 l/ha); sorghum – Dual (86.4% a.i., 2.9 l/ha), Buctril (56% a.i., 1.2 l/ha), Atrazine 4L (43% a.i., 1.2 l/ha); soybeans – Dual (86.4% a.i., 2.9 l/ha), Basagran (42% a.i., 1.8 l/ha), Pinnacle (25% a.i., 17 g/ha); oat/clover – Butyrac 200 (25.9% a.i., 4.7 l/ha)
[f] In 1993, Counter systemic insecticide/nematicide used as corn and sorghum seed treatment, 7.8 kg/ha (15% a.i.); sorghum seed treated with Captan and Lindane

Nematode community structure was determined once management practices had been implemented for 18 years continuously to determine the long-term effect of practices on nematode community composition. Six soil cores (0–15 cm depth, 2 cm diameter) were collected from random locations within crop rows and combined to form one composite sample per experimental subunit in September 1993, near crop maturity. Sampling time and intensity was comparable to other studies implementing nematode community indicators on a regional or national geographical scale (Neher et al. 1995, 1998). Samples were maintained at existing field moisture levels in insulated containers and shipped by overnight mail to Soil Foodweb, Inc. (Corvallis, Oregon) for analysis of nematodes, bacterial biomass and fungal biomass. Nematodes were extracted from a 5 g subsample from each composite soil sample using Baermann funnels (Ayoub 1980). Nematodes were identified to genus according to Bongers (1987) and trophic groups were assigned according to Yeates et al. (1993a). An additional 1 g subsample of soil was removed from each composite sample for measurement of microbial biomass by direct microscopy (Babiuk & Paul 1970). Total bacterial biomass was determined by counting populations and measuring the diameters of all bacteria. Active bacteria biomass was determined according to Lodge & Ingham (1991). Active fungal biomass was determined by measuring the length and diameter of FDA-stained hyphae (Ingham & Klein 1984; Lodge & Ingham 1991). All laboratory bioassays were performed on fresh soil, initiated within 48 hours of sampling. Percent organic matter content of each soil sample was determined by the Soil and Plant Analysis Laboratory (Lincoln, Nebraska).

Eleven indices were calculated to describe nematode community structure. All of the indices have been tested previously (e.g., Bongers 1990; Ettema & Bongers 1993; Freckman & Ettema 1993; Yeates 1994; Neher & Campbell 1994, 1996; Neher et al. 1995): 1) numbers of bacterivores, 2) numbers of fungivores, 3) ratio of fungivores to bacterivores defined as [fungivores/fungivores + bacterivores] (*sensu* Yeates et al. 1993b), 4) numbers of plant-parasites, 5) trophic group diversity with N1 = exp $[-\sum P_i(\ln P_i)]$, where P_i is the proportion of trophic group i in the total nematode community (Shannon & Weaver 1949), 6) maturity index MI1-5 (Bongers 1990), 7) MI2-5 (Bongers et al. 1995), 8) plant-parasitic maturity (PPI) (Bongers 1990), 9) maturity index ratio (PPI:MI) (Bongers et al. 1997), 10) percentage of total free-living nematodes that were assigned a *c-p* value of 2 (early successional) (Bongers et al. 1995), and 11) percentage of free-living nematodes assigned a *c-p* value of 4-5 (later successional) (Bongers et al. 1995).

An unbalanced Kruskal-Wallis test using an incomplete factorial design was performed using nematode index values as dependent variables (SAS 1989). A nonparametric test was used because numbers and indices were not distributed normally. Main effects (experimental blocks, management practice, and the 1993 crop), but not interactions between main effects, were treated as independent variables. Experimental subunits were analyzed initially as separate observations, but later averaged because there was no added benefit of having two rather than one observation per experimental unit. Single degree of freedom contrasts were used to identify effects of nutrient source (O versus F, HF and HFI), herbicides (F versus FH and HFI), and insecticides (HF versus HFI).

Results

Farming system ($p < 0.05$), but not crop present at time of sampling ($p > 0.10$), affected the composition of nematode communities. The most abundant trophic group for all management practices was bacterivores (Table 2). Numbers of bacterivores ($p = 0.0483$) and plant-parasites ($p = 0.0007$) were greater in systems with manure (i.e., O) than without manure (i.e., F, HF and HFI). Additions of herbicides or insecticides did not change numbers of bacterivores ($p = 0.7488$). Fungivores tended to be more abundant in systems with herbicides and/or insecticides (HF and HFI) than with mineral fertilizer alone (i.e., F) ($p = 0.0687$). Similarly, the fungivore: bacterivore ratio was greater in systems receiving herbicides and/or insecticides than mineral fertilizer alone ($p = 0.0335$) or organic manure ($p = 0.0005$). Numbers of omnivores ($p = 0.9371$) and predators ($p = 0.3853$) were similar among farming systems. Trophic diversity was greater in systems without manure than with manure ($p = 0.0155$).

PPI ($p = 0.0440$) and PPI: MI ($p = 0.0024$) values were greater in systems with manure than without manure. MI2-5 was greater in management practices that excluded herbicides and/or insecticides ($p = 0.0164$); substitution of mineral fertilization with organic manure decreased MI1-5 ($p = 0.0073$) but not MI2-5 ($p = 0.9550$). Systems receiving herbicides and/or insecticides had a larger proportion of free-living nematodes that were *c-p* = 2 than

Table 2. Mean value (± standard e
microbial biomass in soils of four cr

	Index
Nematodes	Bacterivores[b]
	Fungivores[b]
	Fungivores: bacterivores[c]
	Plant-parasites[b]
	Trophic diversity[d]
	Omnivores[b]
	Predators[b]
	MI1-5[e]
	MI2-5[f]
	% c-p = 2[g]
	% c-p = 4-5[h]
	PPI[i]
	PPI:MI[j]
Microbes	Active bacteria[k]
	Total bacteria[k]
	Active fungi[k]
	Total fungi[k]
Soil	% organic matter

[a] number of samples
[b] number of nematodes per g of dry
[c] ratio of proportion of fungivores to
[d] Shannon diversity index of trophic
[e] Maturity Index of free-living nema
[f] Maturity Index of free-living nema
[g] proportion of total free-living nem
[h] proportion of total free-living nem
[i] maturity index of plant-parasitic ne
[j] ratio of maturity of plant-parasitic
[k] µg biomass per g of dry soil

with mineral fertilizer alone ($p = 0$
living nematodes that were *c-p* =

Total fungal biomass (p = 0.02
ted positively with application of
among farming systems ($p > 0.2$
identified in the four treatments (
O, F, HF and HFI treatments, resp
ments were *Aphelenchus, Euceph*
and *Protorhabditis*. There were n
of individual nematode genera e
hystera and *Mylonchulus*. Numbe
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tylenchus abundance decreased p
($p = 0.0012$), and insecticides ($p =$
chulus ($p = 0.0267$) abundance in

ent practices had been implemented
ices on nematode community com-
cted from random locations within
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Table 2. Mean value (± standard error) for selected indices of nematode community structure and microbial biomass in soils of four crop management systems (Table 1)

		Management System			
	Index	*O*(n^a=32)	*F*(*n*=30)	*HF*(*n*=31)	*HFI*(*n*=8)
Nematodes	Bacterivores[b]	40.2(10.6)	16.6(3.5)	22.2(4.9)	12.8(2.5)
	Fungivores[b]	7.8(1.7)	7.6(1.6)	14.7(2.5)	10.3(3.6)
	Fungivores: bacterivores[c]	0.2(0.0)	0.3(0.0)	0.4 (0.0)	0.4(0.1)
	Plant-parasites[b]	37.8(6.7)	19.7(3.5)	20.5(4.9)	6.9(1.9)
	Trophic diversity[d]	2.7(0.1)	2.9(0.1)	3.0(0.1)	3.2(0.2)
	Omnivores[b]	0.8(0.3)	1.1(0.4)	0.8(0.3)	0.8(0.4)
	Predators[b]	2.9(0.6)	2.7(0.8)	2.7(0.8)	0.6(0.3)
	MI1-5[e]	2.1(0.1)	2.5(0.1)	2.2(0.1)	2.3(0.1)
	MI2-5[f]	2.6(0.1)	2.8(0.1)	2.4(0.1)	2.5(0.1)
	% c-p = 2[g]	47.1(4.3)	45.5(54.6)	66.5(2.9)	64.7(7.3)
	% c-p = 4-5[h]	18.0(3.3)	27.7(4.7)	20.9(5.4)	25.0(6 5)
	PPI[i]	2.8(0.0)	2.7(0.1)	2.7(0.1)	2.6(0.3)
	PPI:MI[j]	1.4(0.1)	1.2(0.2)	1.2(0.0)	1.1(0.1)
Microbes	Active bacteria[k]	3.6(0.3)	4.1(0.4)	3.2(0.3)	4.8(0.6)
	Total bacteria[k]	144.5(17.1)	145.2(20.5)	101.8(11.8)	159.0(86.1)
	Active fungi[k]	8.0(0.9)	10.1(1.1)	7.2(0.9)	8.4(1.2)
	Total fungi[k]	109.4(6.9)	117.3(10.5)	85.8(7.2)	136.3(22.3)
Soil	% organic matter	3.7(0.3)	3.2(0.2)	3.1(0.2)	3.1(0.2)

[a] number of samples
[b] number of nematodes per g of dry soil
[c] ratio of proportion of fungivores to bacterivores
[d] Shannon diversity index of trophic groups
[e] Maturity Index of free-living nematodes (*c-p* = 1-5)
[f] Maturity Index of free-living nematodes (*c-p* = 2-5)
[g] proportion of total free-living nematodes weighted as *c-p* = 2
[h] proportion of total free-living nematodes weighted as *c-p* = 4-5
[i] maturity index of plant-parasitic nematodes (*c-p* = 2-5)
[j] ratio of maturity of plant-parasitic (*c-p* = 2-5) to free-living nematodes (*c-p* = 1-5)
[k] µg biomass per g of dry soil

with mineral fertilizer alone (p= 0.0022). There were no differences in the proportion of free-living nematodes that were *c-p* = 4-5 ($p = 0.2575$).

Total fungal biomass (p = 0.0269) and active bacterial biomass (p = 0.0579) were associated positively with application of insecticides. Active fungi and total bacteria were similar among farming systems ($p > 0.20$). Fifty-seven nematode genera in thirty-six families were identified in the four treatments (Table 3). Forty-nine, 43, 46 and 30 genera were present in O, F, HF and HFI treatments, respectively. The most abundant nematode genera on all treatments were *Aphelenchus, Eucephalobus, Filenchus, Helicotylenchus, Mesorhabditis, Plectus* and *Protorhabditis*. There were no significant effects of management practice on abundance of individual nematode genera except *Helicotylenchus, Pratylenchus, Cephalobus, Monhystera* and *Mylonchulus*. Numbers of *Pratylenchus* increased ($p = 0.0040$) and *Cephalobus* ($p = 0.0001$) decreased with applications of manure compared to mineral fertilizers. *Helicotylenchus* abundance decreased progressively with mineral fertilizer ($p = 0.0001$), herbicides ($p = 0.0012$), and insecticides ($p = 0.0060$). In contrast, *Monhystera* ($p = 0.0060$) and *Mylonchulus* ($p = 0.0267$) abundance increased with insecticide application.

Table 3. Mean number of nematodes per g of dry soil (± standard error) in soils of four crop management systems (Table 1)

Trophic group/ Family/Genus	c-p[a]	Management System O(*n*[b]=32)	F(*n*=32)	HF(*n*=32)	HFI(*n*=8)
Bacterivores					
Alaimus	4	0.10(0.05)	0.10(0.04)	0.09(0.04)	0.00(0.00)
Cephalobidae	2				
Acrobeles		0.05(0.03)	0.03(0.02)	0.13(0.06)	0.05(0.05)
Acrobeloides		0.04(0.03)	0.02(0.02)	0.03(0.02)	0.00(0.00)
Cephalobus		0.57(0.21)	0.14(0.05)	0.46(0.11)	0.39(0.17)
Chiloplacus		0.04(0.04)	0.02(0.02)	0.00(0.00)	0.00(0.00)
Eucephalobus		1.46(0.48)	0.98(0.23)	0.98(0.31)	1.02(0.35)
Cylindrolaimus	3	0.18(0.08)	0.14(0.05)	0.13(0.06)	0.00(0.00)
Diplogasteridae	1				
Diplogaster		0.07(0.05)	0.02(0.02)	0.01(0.01)	0.00(0.00)
Mesodiplogaster		0.04(0.04)	0.02(0.02)	0.04(0.03)	0.19(0.16)
Monhysteridae	1				
Eumonhystera		0.53(0.14)	0.47(0.16)	0.43(0.16)	0.04(0.04)
Monhystera		0.00(0.00)	0.00(0.00)	0.00(0.00)	0.03(0.03)
Odontolaimus	3	0.03(0.02)	0.04(0.03)	0.00(0.00)	0.00(0.00)
Panagrolaimus	1	0.03(0.03)	0.00(0.00)	0.15(0.09)	0.00(0.00)
Plectidae	2				
Anaplectus		0.10(0.09)	0.00(0.00)	0.03(0.03)	0.03(0.03)
Plectus		0.72(0.18)	0.50(0.13)	1.11(0.42)	0.57(0.33)
Wilsonema		0.00(0.00)	0.00(0.00)	0.06(0.05)	0.00(0.00)
Pristionchus	3	0.05(0.04)	0.03(0.02)	0.02(0.01)	0.03(0.03)
Prismatolaimus	3	0.02(0.01)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Rhabditidae	1				
Mesorhabditis		2.35(1.86)	0.04(0.02)	0.56(0.31)	0.21(0.11)
Parisitorhabditis		0.00(0.00)	0.00(0.00)	0.01(0.01)	0.00(0.00)
Protorhabditis		1.52(0.69)	0.72(0.62)	0.01(0.01)	0.00(0.00)
Rhabdolaimus	3	0.14(0.07)	0.05(0.04)	0.07(0.04)	0.03(0.03)
Teratocephalobus	3	0.03(0.03)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Fungivores					
Aphelenchoides	2	0 33(009)	0.23(0.10)	0.28(0.08)	0.47(0.23)
Aphelenchus	2	0.71(0.17)	0.89(0.24)	1.71(0.35)	0.65(0.29)
Diphtherophora	3	0.04(0.03)	0.07(0.03)	0.02(0.01)	0.03(0.03)
Hexatylus	2	0.00(0.00)	0.00(0.00)	0.07(0.07)	0.00(0.00)
Nothotylenchus	2	0.21(0.17)	0.05(0.04)	0.38(0.24)	0.31(0.31)
Tylencholaimellus	4	0.00(0.00)	0.07(0.07)	0.00(0.00)	0.00(0.00)
Tylencholaimus	4	0.27(0.13)	0.21(0.05)	0.39(0.14)	0.61(0.28)
Plant-parasites					
Axonchium	5	0.01(0.01)	0.00(0.00)	0.01(0.01)	0.03(0.03)
Helicotylenchus	3	4.17(0.90)	1.57(0.34)	1.27(0.32)	0.24(0.20)
Paratylenchus	2	0.27(0.19)	0.21(0.18)	0.13(0.06)	0.00(0.00)
Pratylenchidae	3				
Pratylenchoides		0.31(0.16)	0.17(0.09)	0.03(0.02)	0.05(0.05)
Pratylenchus		0.97(0.32)	0.16(0.06)	0.43(0.09)	0.12(0.06)
Psilenchus	2	0.14(0.07)	0.28(0.14)	0.09(0.04)	0.03(0.03)
Pungentus	4	0.00(0.00)	0.00(0.00)	0.02(0.02)	0.00(0.00)
Telotylenchus	3	0.01(0.01)	0.04(0.03)	0.03(0.03)	0.00(0.00)
Tylenchidae	2				
Boleodorus		0.10(0.10)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Filenchus		0.94(0.28)	0.74(0.24)	1.05(0.32)	0.43(0.30)
Malenchus		0.00(0.00)	0.04(0.04)	0.00(0.00)	0.00(0.00)
Neopsilenchus		0.01(0.01)	0.00(0.00)	0.03(0.03)	0.00(0.00)
Tylenchus		0.40(0.15)	0.51(0.16)	0.26(0.13)	0.42(0.22)
Tylenchorhynchus	3				
Xiphinema	5				
Predators					
Aporcelaimidae	5				
Aporcelaimellus					
Aporcelaimus					
Discolaimidae	5				
Discolaimum					
Discolaimus					
Eudorylaimus	4				
Mononchidae	4				
Clarkus					
Coomansus					
Mylonchulus					
Omnivores					
Enchodellus	4				
Microdorylaimus	4				

[a] Bongers(1990)
[b] number of samples

Discussion

Management practices affecte
crop. Crop-specific pathogens s
poral rotation between host ar
munity indices are sensitive to r
These are important criteria for
or national environmental moni
management regimes and not sl

Differences in nematode co
management-related differences
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Only one component of a mana
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dicted. Numbers of bacterivor
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organic matter and microbes, a
Weiss & Larink 1991). An inc
fungivores: bacterivores (Freck
results of this study contrast tho
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ter than without.

Opposite of our predictions,
than mineral fertilizer. In the O
and trophic index values were si
rasitic nematodes to decrease wi
& Ettema 1993; Griffiths et al.
lity and quantity of the organic r
pact on pathogen populations.
tween organic and conventiona

error) in soils of four crop manage-

tem	
HF(*n*=32)	HFI(*n*=8)
0.09(0.04)	0.00(0.00)
0.13(0.06)	0.05(0.05)
0.03(0.02)	0.00(0.00)
0.46(0.11)	0.39(0.17)
0.00(0.00)	0.00(0.00)
0.98(0.31)	1.02(0.35)
0.13(0.06)	0.00(0.00)
0.01(0.01)	0.00(0.00)
0.04(0.03)	0.19(0.16)
0.43(0.16)	0.04(0.04)
0.00(0.00)	0.03(0.03)
0.00(0.00)	0.00(0.00)
0.15(0.09)	0.00(0.00)
0.03(0.03)	0.03(0.03)
1.11(0.42)	0.57(0.33)
0.06(0.05)	0.00(0.00)
0.02(0.01)	0.03(0.03)
0.00(0.00)	0.00(0.00)
0.56(0.31)	0.21(0.11)
0.01(0.01)	0.00(0.00)
0.01(0.01)	0.00(0.00)
0.07(0.04)	0.03(0.03)
0.00(0.00)	0.00(0.00)
0.28(0.08)	0.47(0.23)
1.71(0.35)	0.65(0.29)
0.02(0.01)	0.03(0.03)
0.07(0.07)	0.00(0.00)
0.38(0.24)	0.31(0.31)
0.00(0.00)	0.00(0.00)
0.39(0.14)	0.61(0.28)
0.01(0.01)	0.03(0.03)
1.27(0.32)	0.24(0.20)
0.13(0.06)	0.00(0.00)
0.03(0.02)	0.05(0.05)
0.43(0.09)	0.12(0.06)
0.09(0.04)	0.03(0.03)
0.02(0.02)	0.00(0.00)
0.03(0.03)	0.00(0.00)
0.00(0.00)	0.00(0.00)
1.05(0.32)	0.43(0.30)
0.00(0.00)	0.00(0.00)
0.03(0.03)	0.00(0.00)
0.26(0.13)	0.42(0.22)

Trophic group/		Management System			
Family/Genus	c-p[a]	O(*n*[b]=32)	F(*n*=32)	HF(*n*=32)	HFI(*n*=8)
Tylenchorhynchus	3	0.06(0.04)	0.00(0.00)	0.11(0.10)	0.00(0.00)
Xiphinema	5	0.17(0.08)	0.22(0.12)	0.51(0.34)	0.08(0.08)
Predators					
Aporcelaimidae	5				
Aporcelaimellus		0.01(0.01)	0.05(0.03)	0.03(0.03)	0.00(0.00)
Aporcelaimus		0.03(0.02)	0.13(0.06)	0.04(0.02)	0.03(0.03)
Discolaimidae	5				
Discolaimum		0.05(0.04)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Discolaimus		0.17(0.07)	0.04(0.02)	0.03(0.02)	0.00(0.00)
Eudorylaimus	4	0.28(0.11)	0.24(0.11)	0.40(0.16)	0.03(0.03)
Mononchidae	4				
Clarkus		0.01(0.01)	0.04(0.02)	0.03(0.02)	0.00(0.00)
Coomansus		0.02(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Mylonchulus		0.01(0.01)	0.04(0.03)	0.01(0.01)	0.08(0.05)
Omnivores					
Enchodellus	4	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Microdorylaimus	4	0.16(0.06)	0.21(0.08)	0.15(0.05)	0.15(0.08)

[a] Bongers(1990)
[b] number of samples

Discussion

Management practices affected nematode community composition more than the current crop. Crop-specific pathogens such as *Heterodera glycines* did not dominate because of temporal rotation between host and non-host crops. Under these conditions, nematode community indices are sensitive to management practice and not crop species (Neher et al. 1995). These are important criteria for implementation of nematode community indices in regional or national environmental monitoring programs. These results illustrate effects of long-term management regimes and not short-term crop rotations.

Differences in nematode communities among farming systems are frequently due to management-related differences in organic matter inputs and intensity of cultivation. All treatments were cultivated in this study but differed in their source of nutrients and pest control. Only one component of a management system was altered per treatment keeping other variables constant. Our results agree with Wardle et al. (1995) who noted more differences in nematode communities between soils receiving organic mulch and those without mulch. For example, bacterivores were more abundant in soil with organic than mineral fertilizer as predicted. Numbers of bacterivores increase rapidly after organic material is added to soil (Freckman 1988; Ettema & Bongers 1993; Gupta 1994) because they are provided with organic matter and microbes, a source of food for the nematodes (Andrén & Lagerlöf 1983; Weiss & Larink 1991). An increase in bacterivores corresponds with a decreased ratio of fungivores: bacterivores (Freckman & Ettema 1993; Neher & Campbell 1994). Notably, the results of this study contrast those of Porazinska & Coleman (1995) and Yeates et al. (1997) who observed greater ratios of fungivores to bacterivores in soils amended with organic matter than without.

Opposite of our predictions, trophic diversity values were smaller in systems with manure than mineral fertilizer. In the O systems, both bacterivores and plant-parasites were abundant and trophic index values were small. Our results contrast those showing numbers of plant-parasitic nematodes to decrease with organic amendments (e.g., El Titi & Ipach 1989; Freckman & Ettema 1993; Griffiths et al. 1994; Scow et al. 1994; Clark et al. 1998). Perhaps, the quality and quantity of the organic material (Chung et al. 1988) or soil fertility influences the impact on pathogen populations. In another study, trophic diversity failed to differentiate between organic and conventional management practices when both bacterivores and plant-

parasites were abundant in both systems (Neher 1999). We anticipated that trophic diversity was influenced mainly by the presence and/or abundance of uncommon groups such as omnivores, predators and fungivores (Neher et al. 1998). In contrast, this study suggests that trophic diversity was related inversely to the dominance of the most abundant trophic groups, i.e., bacterivores and plant-parasites. Freckman & Ettema (1993) also reported inverse relationships between number of bacterivores and trophic diversity values. Abundance of bacterivores and plant-parasites declined and trophic diversity values increased with applications of herbicides and insecticides. These findings are supported by those of Todd et al. (1992) who demonstrated that insecticide-nematicide carbofuran reduced numbers of plant-parasite and microbivore densities in a prairie system. The method of application affects the severity of impact. For example, the insecticide lindane altered nematode communities for a short duration when applied to soil surfaces, but for longer periods when introduced directly into the soil (Wegorek & Trojanowski 1986). Lindane was applied as a seed coating in this study. Furthermore, mixtures of herbicides with insecticides affect nematodes differently than herbicides alone. Nematodes are also reduced in number by pesticides not designed for nematodes as a target. For example, the fungicide captan and protozoacide fumigillin reduce nematode numbers (Colinas et al. 1994).

In contrast with trophic diversity, values of successional maturity decreased in systems with mineral fertilizer compared to manure. Applications of herbicides and insecticides increased proportions of colonizers (c-p = 2) without significantly decreased proportions of persisters (c-p = 4-5). Earlier colonizers (c-p = 1) were most common with applications of manure. Contemporary agriculture is largely an effort to maintain ecosystems at a more productive, pre-mature successional stage, and nematode communities respond accordingly. Cultivation decreases fungal biomass, and numbers of fungivores and predators (Hendrix et al. 1986; Yeates & Bird 1994; Wardle et al. 1995), shifting ecological succession of cultivated soils to stages less mature than without cultivation (Neher & Campbell 1994; McSorley 1997). Compared to natural ecosystems, systems that are cultivated (Neher & Campbell 1994) and receive organic (Ettema & Bongers 1993) or mineral (Wasilewska 1979) fertilizers reduce nematode species diversity and shift to early successional stages. Apparently, subsequent applications of herbicides and/or insecticides shift nematode communities to a more primary stage than cultivation and/or organic amendments. Although nutrient enrichment affects nematode communities for a short duration (e.g., Yeates 1984; Ettema & Bongers 1993; Yeates & Bird 1994; Wardle et al. 1995), they have minimal impact on nematodes communities over the long term (Dmowska & Ilieva 1995).

This study demonstrates differential effects of pesticides and nutrient source on nematode community composition. Different nematode genera are more sensitive to the form of nutrient enrichment while others are more sensitive to pesticide application. Herbicides may affect abundance of microbes and nematodes indirectly by reducing root growth and inputs of organic matter (Wainwright 1978).

Acknowledgements

We thank Soil Foodweb, Inc. (Corvallis, Oregon USA) for extraction and classification of nematodes and quantification of microbial biomass, and the Soil and Plant Analysis Laboratory (Department of Agronomy, University of Nebraska) for estimation of organic matter content. Early versions of the manuscript were reviewed by T. Bongers, J. W. Doran, R. Drijber, R. McSorley, and G. W. Yeates.

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Pedobiologia **43**, 439–452 (1999)
Urban & Fischer Verlag
http://www.urbanfischer.de/journals

Larval dynamics in an a

Tom Gittings[1] and Paul Giller

Dept. of Zoology and Animal Ecolo

Accepted: 27. August 1999

Summary. The larval dynamics
tored over a full year's activity p
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Key words: Dung beetles; *Apho*
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Introduction

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