Chin. Geogra. Sci. 2010 20(2) 106–111
DOI: 10.1007/s11769-010-0106-0

Vertical Distribution of Soil Nematode Communities under Different Tillage Systems in Lower Reaches of Liaohe River

HOU Xuekun[1, 2], HU Ning[3], ZHANG Xiaoke[1], LIANG Lei[3], ZHAI Ruichang[2]

(*1. Liaoning Key Laboratory of Soil Environmental Quality and Agro-product Safety, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China; 2. College of Plant Sciences and Technology, Heilongjiang August First Reclamation University, Daqing 163319, China; 3. College of Resources and Environment, Liaoning University, Shenyang 110036, China*)

Abstract: Vertical distribution of soil nematode communities under conventional tillage (CT), no-tillage (NT) and fallow field (FF) treatments in the Lower Reaches of the Liaohe River was investigated at six soil depths (0–5 cm, 5–15 cm, 15–30 cm, 30–50 cm, 50–75 cm and 75–100 cm). The results show that total nematode abundance gradually decreases with depth, and the highest number of total nematodes is observed at 0–5 cm depth under NT and FF treatments. The number of fungivores and plant parasites is significantly higher under FF and NT treatments than under CT treatment at the 0–5 cm depth. There is significant soil depth effect on the abundances of bacterivores and omnivores-predators, which exhibits a similar trend to that of total nematodes; whereas, no significant tillage effect is found. Tillage effect on soil nematode communities can be reflected by values of relative tillage response of index *V*. Results of index *V* indicate that total nematodes, bacterivores, fungivores and plant parasites are mildly inhibited, and omnivores-predators is moderately inhibited under CT treatment; while, under FF treatment total nematodes is mildly, and fungivores and plant parasites are moderately stimulated, respectively.

Keywords: soil nematode; tillage system; vertical distribution; tillage response

1 Introduction

Tillage as the major disturbance to soil causes the redistribution of plant residues and soil organic matter and affects soil fauna community structure (Fu *et al*., 2000). Different tillage practices with vastly different disturbance regimes have an effect on the detritus food web (Wardle, 1995). Soil nematodes are one of major components of the detritus food web and can regulate residue decomposition and nutrient release through their high turnover rates and their interactions with microflora (Ferris *et al*., 2001). They are exposed to a full range of soil structural change because they spend their whole life cycle in the soil (Ritz and Trudgill, 1999). Therefore, soil disturbance from tillage practices can influence soil nematode community composition and diversity.

It has been reported that tillage has impacts on soil nematode communities, and the changes in the soil environments imposed by tillage practices have been indicated by nematode community analysis in recent years (Masse *et al*., 2002; Sánchez-Moreno *et al*., 2006; Govaerts *et al*., 2007; Minoshima *et al*., 2007; Rahman *et al*., 2007; Mendoza *et al*., 2008; Moebius-Clune *et al*., 2008; García-Ruiz *et al*., 2009). Previous studies were restricted mainly to the effect of tillage on soil nematode abundance, trophic structure and generic composition. Total nematode abundance has been found to be either enhanced or reduced by tillage, with both mild and moderate stimulation or inhibition (Wardle, 1995). Mendoza *et al*. (2008) found that total nematode abundance in tillage treatments did not differ significantly throughout a year; however, nematode abundance tended to be more higher in no-tillage treatment than in chisel and plow treatments for the sampling year at Rogers Memorial Farm of the University of Nebraska-Lincoln, USA. Fu *et al*. (2000) reported that bacterivorous nematodes responsed to residue addition

Received date: 2009-07-30; accepted date: 2009-12-07
Foundation item: Under the auspices of Knowledge Innovation Programs of Chinese Academy of Sciences (No. KZCX2-YW-445), the Science and Technology Program of Liaoning Province (No. 2009403053)
Corresponding author: ZHANG Xiaoke. E-mail: zxk@iae.ac.cn

earlier than fungivorous nematodes under conventional and no-tillage agroecosystems in both laboratory and field studies. Minoshima *et al*. (2007) found that omnivorous and predatory nematodes did not increase with no-tillage at the experimental site of the University of California Davis, USA. Govaerts *et al*. (2007) observed that both non-parasitic and parasitic nematodes increased under no-tillage treatment in maize growing season in Central Mexico. With the method of canonical correspondence analysis (CCA), Fiscus and Neher (2002) distinguished distinctive response of nematode genera to tillage and proved that some genera such as *Achronmadora*, *Cephalobus*, *Microdorylaimus*, *etc*. were more sensitive to indirect effects of tillage than direct ones. However, little information is available on the vertical distribution of soil nematode communities under different tillage systems.

The Lower Reaches of the Liaohe River is an important area for food production in Northeast China. In order to further reveal soil carbon sequestration under conservational tillage in this area, understanding spatial patterns of soil biota is necessary. The purposes of this study were to investigate the vertical distribution of soil nematode communities under different tillage systems, and to determine the responses of soil nematodes to tillage disturbance in the Lower Reaches of the Liaohe River, China.

2 Materials and Methods

2.1 Site description

This study was conducted at the Shenyang Experimental Ecological Station, Chinese Academy of Sciences (41°31'N, 123°22'E). The station is situated in the Lower Reaches of the Liaohe River, and located in a continental temperate monsoon zone, with a dry-cold winter and a warm-wet summer. The mean annual temperature is 7℃–8℃, mean annual precipitation is 650–700 mm and the non-frost period is 147–164 days. The test soil is classified as an aquic brown soil (silty loam Hapli-Udic Cambosols in Chinese Soil Taxonomy) (Liang *et al*., 2005).

2.2 Experimental design and soil sampling

Three tillage treatments, i.e., conventional tillage (CT, mouldboard ploughing), no-tillage (NT) and fallow field (FF, unmanaged field lasting for 6 years), were arranged in a completely random design with four replicates (8.5 m×12.0 m each) in October 2002. Maize (*Zea mays*) was planted in the CT and NT plots. Ten days before sowing of maize, the soil in CT plots (without maize stalks from the previous crops) was ploughed to a depth of 25 cm by means of a two-share mouldboard plow. NT plots have not been tilled at all since October 2002, and received 7.8 Mg/(ha·yr) of maize stalks. In FF plots, at the beginning of the trial, maize field was converted to fallow field, where *Eriochloa villosa*, *Abutilon theophrasti* and *Bidens frondosa* were dominant weeds. Soil samples were collected from each plot at depths of 0–5 cm, 5–15 cm, 15–30 cm, 30–50 cm, 50–75 cm and 75–100 cm by a hand auger (6.7 cm diameter) after maize harvest in October 2008.

2.2 Extraction and identification of soil nematodes

Nematodes were extracted from 100 g fresh soil from each sample using the modified cotton–wool filter method (Li *et al*., 2009). The abundance of nematodes was expressed in individuals per 100 cm^3 dry weight soil (based on individuals per unit volume calculated from bulk density) (Ou *et al*., 2005). Nematodes were identified to genus level using an inverted compound microscope. Based on known feeding habits and stoma morphology of soil nematodes, the classification of trophic groups was assigned to bacterial-feeding (BF), fungal-feeding (FF), plant-parasitic (PP) and omnivorous-predaceous (OP) nematodes (Yeates *et al*., 1993).

2.3 Calculation method of index *V*

Index *V* was used to analyze relative tillage response of nematode communities, which can be expressed as Wardle (1995):

$$V_{CT} = 2M_{CT} / (M_{CT} + M_{NT}) - 1 \quad (1)$$

$$V_{FF} = 2M_{FF} / (M_{FF} + M_{NT}) - 1 \quad (2)$$

where V_{CT} and V_{FF} are the relative response indices of nematode trophic groups in CT and FF compared to NT; M_{CT}, M_{FF} and M_{NT} are the abundance of nematodes under the treatments of CT, FF and NT, respectively. *V* ranges from –1 to 1, and positive values indicate stimulation and negative values imply inhibition. When $V<-0.67$, the effect is extreme inhibition; $-0.67<V<-0.33$, moderate inhibition; $-0.33<V<0$, mild inhibition; $0<V<0.33$, mild stimulation; $0.33<V<0.67$, moderate stimulation; $V>0.67$, extreme stimulation (Wardle, 1995).

2.4 Statistical analysis

The significance of the effects of tillage and soil depth on nematode communities was tested by means of a two-way analysis of variance (ANOVA). The significance of the effects of tillage treatments on nematode communities in each soil depth was tested by one-way ANOVA. For all tests, statistically significant differences were assigned to $P<0.05$. All statistical analyses were performed by SPSS software package.

3 Results

3.1 Abundance of total nematodes

The vertical distribution of total nematode abundance under different tillage systems is shown in Fig. 1. In the CT treatment, total nematode abundance increased from 0–5 cm to 5–15 cm, then decreased with depth, and a total of 46.7% of the soil nematodes were at 5–15 cm depth. In the NT and FF treatments, total nematode abundance decreased with depth, and the highest values (3 474 and 5 814 individuals per 100 cm^3 dry soil, respectively) both appear at 0–5 cm depth, with 68.6% of total nematodes in NT and 57.0% in FF, respectively. Significant differences in the total nematode abundance at 0–5 cm depth were found among different tillage systems. Significant effects of depth and tillage, and interaction effect of both on the total nematode abundance were found by two-way ANOVA ($P<0.01$) (Table 1).

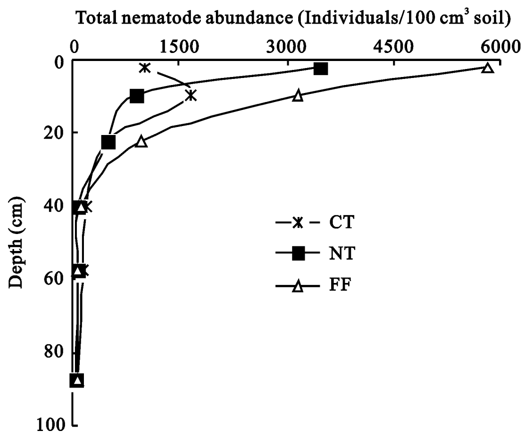


Fig. 1 Vertical distribution of total nematode abundance under different tillage systems

3.2 Abundance of nematode trophic groups

The vertical distribution of nematode trophic groups under different tillage systems is shown in Fig. 2. The abundance of bacterivores exhibited a similar trend with that of total nematodes. Significant depth effect was found on the abundance of bacterial-feeding nematode, but no tillage effect was found. The abundance of fungal-feeding nematode decreased with depth under different tillage systems, and at the 0–5 cm depth it was significantly higher in FF treatment than in the CT and NT treatments ($P<0.05$). Fungivores were significantly affected by depth, tillage and their interaction effect ($P<0.01$) (Table 1).

Table 1 Two-way ANOVA (F-values) for total nematode abundance and trophic groups

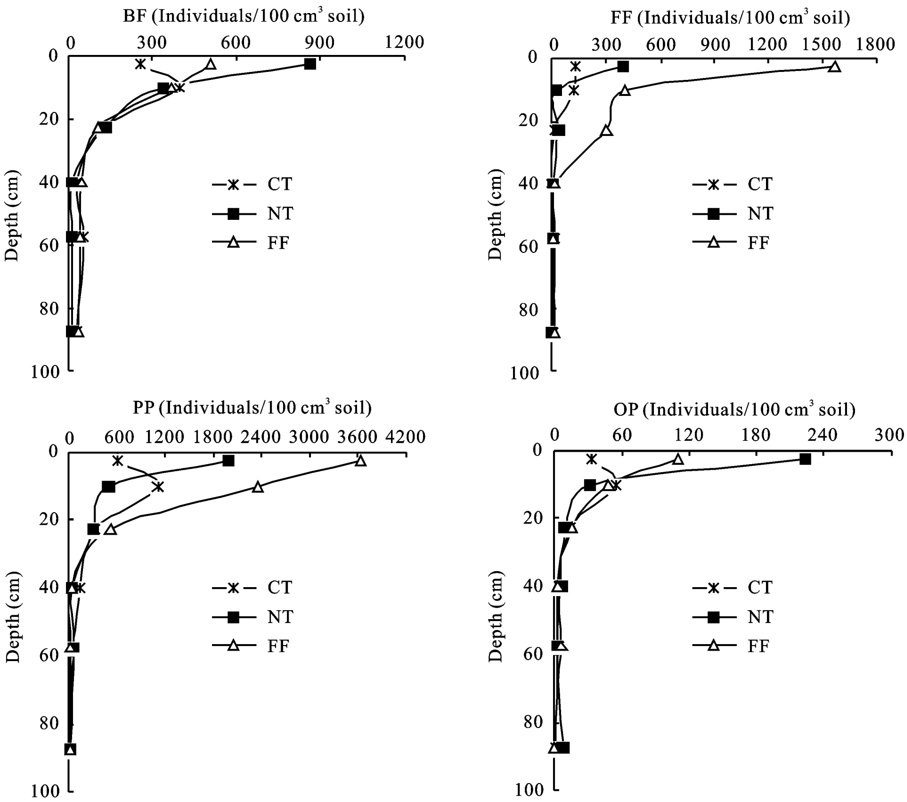
	Tillage	Depth	Tillage × Depth
T_{nem}	7.79**	21.60**	3.88**
BF	0.66	9.29**	1.18
FF	13.75**	13.87**	5.34**
PP	5.60**	13.57**	2.80**
OP	0.85	4.08**	1.10

Notes: T_{nem} denotes total nematodes; BF, FF, PP and OP denote bacterial-feeding, fungal-feeding, plant-parasitic and omnivorous-predaceous nematodes, respectively; the *df* values for depth, treatment and Depth × Treatment were 5, 2 and 10, respectively. ** $P<0.01$

The abundance of plant parasites and omnivores-predators decreased with depth in the NT and FF treatments (Fig. 2). In CT treatment, most plant parasites and omnivores-predators were distributed at the 5–15 cm depth and exhibited decreasing trend from the 5–15 cm to 75–100 cm. The abundance of plant parasites at the 0–5 cm depth was significantly lower in the CT treatment than in the FF treatment ($P<0.05$). Significant depth effect, tillage effect and interaction effect of both on plant parasites were found in this study ($P<0.01$) (Table 1). Significant differences in the omnivores-predators were only observed among different depths.

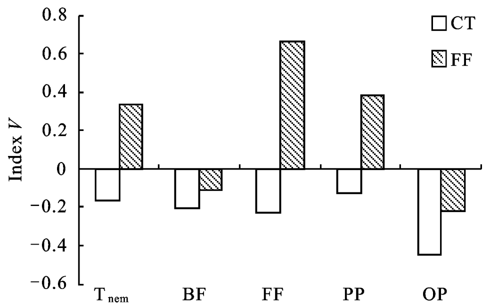
3.3 Relative response of trophic groups to tillage disturbance

The values of relative tillage response of index V are shown in Fig. 3. The values of V_{CT} in total nematodes, bacterivores, fungivores and plant parasites were all between –0.33 and 0, which indicated that they were mildly inhibited by CT treatment; V_{CT} in omnivores-predators were –0.45, which proved that this trophic group was moderately inhibited by CT treatment. The values of V_{FF} in total nematodes were between 0 and 0.33 and those of fungivores and plant parasites were between 0.33 and 0.67, which indicated that they were mildly and moderately stimulated by the FF treatment, respectively.



BF, FF, PP and OP denote bacterial-feeding, fungal-feeding, plant-parasitic and omnivorous-predaceous nematodes, respectively

Fig. 2 Vertical distribution of nematode trophic groups abundance under different tillage systems



T_{nem} denotes total nematodes; BF, FF, PP and OP denote bacterial-feeding, fungal-feeding, plant-parasitic and omnivorous-predaceous nematodes, respectively

Fig. 3 Values of index *V* for total nematodes and trophic groups

4 Discussion

A gradual decrease trend in the total nematode abundance with depth was found under different tillage systems, which indicated stratification of the biological activity within the soil profile. Similar trends were also observed under different land use types down to 150 cm at the same study area (Ou *et al.*, 2005). In this study, the soil nematodes at 0–5 cm depth were more abundant in the NT and FF treatments than in the CT treatment. The result was similar with that of Fu *et al.* (2000) in a field study at the Horseshore Bend experimental area, Georgia, USA. It is well-known that no-tillage practice increases more soil organic matter content in the surface layer than conventional tillage does (Feng *et al.*, 2003). The distribution of nematodes in the soil profile largely depends on the distribution of soil organic carbon (Ou *et al.*, 2005). It was one reason why more total nematodes was under no-tillage than under conventional tillage in the surface layer. Another reason might be that the soil nematodes were sensitive to tillage disturbance (Wardle, 1995), which resulted in the reduction of their number under conventional tillage. The fallow field with relatively fewer disturbances offered the friendly survival environments for soil nematodes.

Frequent tillage may affect the soil ecosystem by changing the nematode trophic structure (Fu *et al.*, 2000). The abundance of bacterivores responded clearly to soil depth, but not to tillage practices. Fungivores were stimulated in fallow field at the 0–5 cm depth. These results were in agreement with that reported by López-Fando and Bello (1995), who found no significant difference in bacterial-feeding nematodes between virgin and cultivated area, and the abundance of fungivores was highest at virgin site. Ferris *et al*. (2004) documented that bacterivorous and fungivorous nematodes were constrained by environmental conditions and resource availability. In this study, plant parasites responded significantly to tillage practices and depth effect. The distribution of plant-feeding nematodes in the soil profile might be reflected by the distribution of plant roots (Verschoor *et al*., 2001). However, omnivores-predators were not significantly affected by tillage, but by depth effect. This result was similar to that reported by Minoshima *et al*. (2007) at the experimental site of the University of California Davis, USA. The vertical distribution for different nematode trophic groups might be due to distribution differences of their food sources or competitive interactions for resources (Fu *et al*., 2000).

The values of index *V* were used to represent the relative difference in abundance of soil nematodes in different tillage systems. The Results showed that total nematodes and their four trophic groups were all inhibited by CT treatment, while total nematodes, fungivores and plant parasites were stimulated by FF treatment when comparing with NT treatment. No-tillage system had greater biological complexity, and it approached the structure of "natural" ecosystems (such as fallow field) more closely than conventional tillage system did. (Kladivko, 2001). The response of soil nematodes to tillage varied depending on their trophic groups (Sánchez-Moreno *et al*., 2006).

5 Conclusions

In this study, it can be concluded that soil depth and tillage were main factors influencing the distribution of soil nematode communities. Total nematode number reduced due to conventional tillage. The nematodes showed variable responses to different tillage practices at trophic levels. Fungivores benefited from fallow field, resulting in the increase of their abundance. The depth effect on bacterivores and omnivores-predators was much stronger than tillage effect. The values of V_{CT} in total nematodes, bacterivores, fungivores and plant parasites were all between –0.33 and 0, revealing that they were mildly inhibited under CT treatment; and those in omnivores-predators were –0.45, exhibiting that this trophic group was moderately inhibited under CT treatment. The values of V_{FF} in total nematodes were between 0 and 0.33 and those in fungivores and plant parasites were between 0.33 and 0.67, which indicated that they were mildly and moderately stimulated by FF treatment, respectively.

Appropriate fallow and reducing tillage are the efficient cultural practice for soil organisms′ maintenance and sustainable agriculture development. Tillage and depth effect can be indicated by nematode trophic groups and total abundance. However, functional guilds of soil nematodes are more relevant to agricultural production and sustainability in different tillage systems. Therefore, further studies on nematode functional guilds to tillage disturbance are necessary.

Acknowledgements

The authors would like to thank Prof. Wasim Ahmad (Nematode Biodiversity Research Laboratory, Aligarh Muslim University, India) and Prof. Liang Wenju (Institute of Applied Ecology, Chinese Academy of Sciences, China) for their constructive proposal of this manuscript.

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