Vertical distribution of soil nematodes under different land use types in an aquic brown soil

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Summary
A field investigation was conducted at the Shenyang Experimental Station of Ecology to study the vertical distribution of nematode communities down to a depth of 150 cm under four land use types (paddy field, maize field, fallow field and woodland) in an aquic brown soil of Northeast China. The results showed that the numbers of total nematodes and trophic groups exhibited a gradual decrease trend with depth under different land use types. The numbers of total nematodes, bacterivores, fungivores, and plant parasites were positively correlated with the contents of TOC, total N, and alkali N in the four land use types. The majority of nematodes were present in the 0–30 cm soil layers. No significant effects were found on the number of total nematodes at all depths among the maize field, fallow field and woodland. Bacterivores were found to be the most abundant group in the paddy field, while plant parasites were observed to be the most abundant group in the maize field, fallow field and woodland. The number of fungivores at the depths of 0–5 and 5–10 cm was higher in the maize field than in the other land use types. Omnivores-predators were found in relatively low numbers under each land use type, with a higher presence in the fallow field and woodland at the depths of 0–5, 5–10, 10–20 cm compared with the paddy and maize fields. 54 genera were observed throughout the four land use types in our study. The woodland treatment supporting greater basal resource inputs tended to result in a higher diversity of nematodes. The number of genera reached a maximum at the depth of 5–10 cm under each land use type. The faunal profiles showed that soil food webs in the fallow field and woodland were structured, and those in the paddy and maize fields were stressed. The faunal analysis provided a useful tool for diagnostic interpretation of the condition of upper soil layers.

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Introduction

Since the 1990s, issues of sustainable land use have received increasing attention. The research on relationships between land use and soil organisms is essential for better understanding soil ecosystem process and adaptive ecosystem management. Changes in soil faunal communities caused by differing land use influence the function of soil ecosystem through modifying food web structure and decomposition pathway (Wu et al., 2002). Generally, nematode communities can reflect the differences between undisturbed and disturbed environments (Yeates and King, 1997; Liang et al., 2003). Changes in the soil environment imposed by land use practices have been revealed by measures of nematode community patterns in recent years (Wu et al., 2002; Masse et al., 2002).

Nematodes represent a central position in the soil food web (Neher, 2001). Nematode population dynamics provide an insight into the structure and function of soil food webs (Bongers and Bongers, 1998). Knowledge of spatial patterns of nematodes contributes to better understanding of belowground fauna community structure and functioning (Lazarova et al., 2004). It has been shown that many nematode genera exhibit a typical vertical distribution, which often relates to a variety of biological, physical and chemical variables (López-Fando and Bello, 1995; Liang et al., 1999). Gradual reductions of nematode abundance and diversity, and changes in the distribution of genus and trophic group composition have been observed with increasing soil depth (Yeates, 1980; Yeates et al., 2000; Lazarova et al., 2004). An understanding of how soil nematodes change at a vertical scale under different land use types is important in interpreting the impact of this land use on soil processes and assessing its sustainability.

Therefore, more evidence of vertical distribution on how different land use patterns affect soil ecosystem process and shape alteration of biodiversity is required. This study seeks to relate variation in the soil nematode community to land use types under the general hypothesis that each form of land use practices has a corresponding effect on the soil nematode community, and that the amplitude of the effect is greatly related to the degree of anthropogenic disturbances and rooting patterns. The objectives of this study were: to characterize the vertical distribution of nematode communities in soils exposed to different land use types (paddy field, maize field, fallow field and woodland); to assess the impact of land use types on the enrichment index (EI) and structure index (SI) descriptors of the soil food web.

Materials and methods

Field site

This study was conducted at the Shenyang Experimental Station of Ecology (41°31’N, 123°22’E), Chinese Academy of Sciences, a Chinese Ecosystem Research Network (CERN) site at Sujiatun District, Shenyang Municipality, Northeast China. The station is located in the continental temperate monsoon zone, with a dry-cold winter and a warm-wet summer. The annual mean temperature is 7.0–8.0 °C, annual precipitation averages 650–700 mm, and annual non-frost period is 147–164 days. The soil at the study site is classified as aquic brown soil (silty loam Hapli-Udic Cambisols in Chinese Soil Taxonomy) (Cooperative Research Group on Chinese Soil Taxonomy, 2001), which is suitable for growing maize, soybean, and rice.

The Shenyang Experimental Station of Ecology was established in 1990. The area is a formerly arable field used for growing rice. Four land use types, i.e., paddy field (Oryza sativa L.), maize field (Zea mays L.), fallow field and woodland (Populus canadensis), were imposed in 1990 and continued to our sampling in 2003.

Soil sampling

Soil samples were collected from three plots (25 m² each) of every treatment at depths of 0–5, 5–10, 10–20, 20–30, 30–40, 40–60, 60–80, 80–100, 100–120, and 120–150 cm in November 2003 (post-harvest). Each soil sample comprised 5 cores (5 cm diameter); subsamples were taken from each such bulk sample for estimation of nematode populations. Samples collected were kept at 4 °C before analysis.

Physico-chemical measurements

Soil bulk density was determined by using stainless steel ring and oven-dried at 105 °C. Soil total organic carbon (TOC), total nitrogen, alkali nitrogen, total P and Olsen-P under the four land use types were measured by Zhang et al. (2004a, b).

Biological measurements

Nematodes were extracted from 100 g (fresh weight) of soil from each sample using sugar flotation and centrifugation (Liang et al., 1999; Steinberger et al., 2001), the nematode populations were expressed per 100 g dry weight soil. All
extracted nematodes in each sample were counted and identified, mainly to genus level if possible, using an inverted compound microscope. The classification of trophic groups was assigned to: (1) bacterivores; (2) fungivores; (3) plant-parasites; and (4) omnivores-predators, based on known feeding habitats or stoma and esophageal morphology (Yeates et al., 1993; Liang et al., 1999, 2001).

Nematode faunal analyses

Nematode faunal analyses were conducted as indicators of food web structure, functioning and resource availability (Ferris et al., 2001, 2004; Ferris and Matute, 2003), interpreting the structure-enrichment conditions of the food web. The EI is calculated as $EI = 100(e/(e + b))$, where $e$ is the abundance of individuals in guilds in the enrichment component weighted by their respective $K_e$ values and $b$ the abundance of individuals in the basal component weighted by their $K_b$ values. The EI provides an indicator of resources available to the soil food web and the response of primary decomposers to those resources. The SI is calculated as $SI = 100(s/(s + b))$, where $s$ is the abundance of individuals in the structure component weighted by their $K_s$ values. A higher SI value suggests a food web with more trophic linkages. The basal index (BI) is calculated as $BI = 100(b/(b + e + s))$. BI may appeared to be most valuable as indicators for the health status of a soil (Berkelmans et al., 2003).

Statistical analysis

All the data were subjected to statistical analysis of variance (ANOVA) in the SPSS statistical package. Differences with $P < 0.05$ were considered significant.

Results

The number of total nematodes

Under each land use type, a gradual decrease trend was observed in the number of total nematodes from 0–5 to 120–150 cm (Fig. 1A). The number of total nematodes decreased to less than 25 individuals 100 g$^{-1}$ dry soil at 20–30 cm depth in paddy field, at 60–80 cm depth in woodland, and at 80–100 cm depth in fallow and maize fields. The number of total nematodes from 0–5 cm to 80–100 cm was found to be significantly lower ($P < 0.05$) in paddy field than in others. No significant differences were found among the maize field, fallow field and woodland at all depths from 0–5 to 120–150 cm. More than 82% of soil nematodes were present in 0–30 cm layers in the paddy field, fallow field and woodland, while 75% of soil nematodes were present at the depth of 0–30 cm in the maize field. The number of total nematodes was positively correlated with the contents of TOC, total N and alkali N under the four land use types. The number of total nematodes was not significantly correlated with total P in the maize field, fallow field and woodland (Table 1). Fig. 1B, based on individuals per unit volume calculated from bulk density, described a similar trend with Fig. 1A.

Trophic groups

Bacterivores were found to be the most abundant group in the paddy field, while plant parasites were observed to be the most abundant group in the maize field, fallow field and woodland.
Significant differences (P < 0.05) in the number of bacterivores from 0–5 to 30–40 cm depth were found among the four treatments (Fig. 2). The number of bacterivores decreased to less than 10 individuals 100 g−1 dry soil at 20–30 cm depth in the paddy field and at 80–100 cm depth in the maize field, fallow field and woodland. A gradual decrease trend in the number of bacterivores from 0–5 to 120–150 cm was observed in the maize field. More than 80% of bacterivores were present in 0–30 cm layers in the maize field, fallow field and woodland. In paddy field, 74% of bacterivores were present in 0–30 cm soil layers.

Significant differences (P < 0.05) in the number of fungivores at the depths of 0–5 and 5–10 cm, respectively. The density of fungivores was low in the paddy field at all depths, less than 3 individuals 100 g−1 dry soil. In the fallow field and woodland, the numbers of fungivores were initially highest at 0–5 cm depth, and then decreased with depth, which subsequently reached the second peak values and then decreased again. A gradual decrease trend in the number of fungivores from 0–5 to 120–150 cm was observed in the maize field. More than 80% of fungivores were present in 0–30 cm layers in the maize field, fallow field and woodland. In paddy field, 74% of fungivores were present in 0–30 cm soil layers.

Significant differences (P < 0.05) in the number of plant parasites were found among the four land use types from 0–5 to 60–80 cm depth (Fig. 2). The number of plant parasites decreased to less than 20 individuals 100 g−1 dry soil under each land use type at 80–100 cm depth. The decrease trend in the number of plant parasites was common with increasing depth for different land use types. The density of plant parasites was low at all depths in the paddy field. In the maize field, fallow field and

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**Table 1.** Correlation coefficients between soil nematodes and soil chemical properties under different land use types

<table>
<thead>
<tr>
<th>Indicator</th>
<th>TOC</th>
<th>Total N</th>
<th>Total P</th>
<th>Alkali N</th>
<th>Olsen-P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paddy field</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TNEM</td>
<td>0.930**</td>
<td>0.920**</td>
<td>0.738**</td>
<td>0.897**</td>
<td>0.249</td>
</tr>
<tr>
<td>BF</td>
<td>0.779**</td>
<td>0.794**</td>
<td>0.793**</td>
<td>0.705**</td>
<td>0.150</td>
</tr>
<tr>
<td>FF</td>
<td>0.606**</td>
<td>0.588**</td>
<td>0.169</td>
<td>0.546**</td>
<td>–0.071</td>
</tr>
<tr>
<td>PP</td>
<td>0.795**</td>
<td>0.780**</td>
<td>0.641**</td>
<td>0.804**</td>
<td>0.277</td>
</tr>
<tr>
<td>OP</td>
<td>0.558**</td>
<td>0.513**</td>
<td>0.137</td>
<td>0.582**</td>
<td>0.243</td>
</tr>
<tr>
<td><strong>Maize field</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TNEM</td>
<td>0.844**</td>
<td>0.843**</td>
<td>–0.089</td>
<td>0.892**</td>
<td>–0.166</td>
</tr>
<tr>
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<td>0.764**</td>
<td>–0.161</td>
<td>0.790**</td>
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<td>0.515**</td>
<td>0.078</td>
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<td>0.838**</td>
<td>–0.093</td>
<td>0.875**</td>
<td>–0.147</td>
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<td>0.177</td>
<td>–0.272</td>
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<td><strong>Fallow field</strong></td>
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<tr>
<td>TNEM</td>
<td>0.893**</td>
<td>0.874**</td>
<td>0.278</td>
<td>0.907**</td>
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<tr>
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<td>0.789**</td>
<td>0.293</td>
<td>0.804**</td>
<td>–0.104</td>
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<td>FF</td>
<td>0.613**</td>
<td>0.607**</td>
<td>0.242</td>
<td>0.652**</td>
<td>0.029</td>
</tr>
<tr>
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<td>0.787**</td>
<td>0.300</td>
<td>0.829**</td>
<td>–0.064</td>
</tr>
<tr>
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<td>0.546**</td>
<td>0.258</td>
<td>0.523**</td>
<td>–0.105</td>
</tr>
<tr>
<td><strong>Woodland</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TNEM</td>
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<td>0.793**</td>
<td>0.106</td>
</tr>
<tr>
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<td>0.490**</td>
<td>–0.226</td>
<td>0.570**</td>
<td>–0.194</td>
</tr>
<tr>
<td>FF</td>
<td>0.549**</td>
<td>0.530**</td>
<td>–0.133</td>
<td>0.624**</td>
<td>–0.134</td>
</tr>
<tr>
<td>PP</td>
<td>0.768**</td>
<td>0.793**</td>
<td>–0.186</td>
<td>0.782**</td>
<td>–0.030</td>
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<tr>
<td>OP</td>
<td>0.551**</td>
<td>0.544**</td>
<td>–0.212</td>
<td>0.618**</td>
<td>–0.204</td>
</tr>
</tbody>
</table>

TNEM, total nematodes; BF, bacterivores; FF, fungivores; PP, plant parasites; OP, omnivores-predators.

*, ** Significant at P < 0.05 and P < 0.01, respectively.
woodland, the numbers of plant parasites were initially highest at 0–5 cm depth, and then decreased with depth, which subsequently reached another peak values and then decreased again. More than 80% of plant parasites were present in 0–30 cm layers in the paddy field, fallow field and woodland, while 75% of plant parasites were present in 0–30 cm layers in the maize field.

The omnivores-predators were found in low numbers under different land use types, with a relatively higher presence in the fallow field and woodland at 0–5, 5–10, 10–20 cm depth in comparison to paddy and maize fields (Fig. 2). Significant differences (P < 0.05) in the number of omnivore-predators were found among different land use types from 0–5 to 30–40 cm depth. A gradual decrease trend in the number of omnivore-predators was found in the fallow field and woodland. The number of omnivores-predators exhibited irregular changes with increasing depth in paddy and maize fields. More than 82% of omnivores-predators were present in 0–30 cm soil layers in the fallow field and woodland. Only 43% of omnivores-predators were present in 0–30 cm soil layers in the maize field.

The numbers of bacterivores, fungivores, and plant parasites were positively correlated with the contents of TOC, total N, and alkali N in the four land use types (Table 1). The numbers of omnivores-predators were positively correlated with the contents of TOC, total N, and alkali N in the paddy field, fallow field and woodland. In the paddy field, the number of bacterivores and plant parasites were positively correlated with the contents of total P (Table 1).

**Nematode richness**

Nematode richness, as indicated by the number of genera (Ekschmitt et al., 2001), reflects biodiversity of soil habitat. Over 54 genera were recorded throughout the four land use types in our study. The woodland had the highest number of genera (39), followed by the fallow field, maize field, paddy field, which yielded 35, 30, 29 genera, respectively.
The number of genera reached maximum at 5–10 cm depth in each land use type, and then decreased with depth (Fig. 3).

Nematode faunal structure

The faunal profiles were constructed for each sampling site based on the relative weighted abundance of nematode guilds. On the whole, the faunal profiles showed that the food webs in the fallow field and woodland were structured, and the environments were little disturbed, because the majority of sites were in quadrat C (Fig. 4). In addition, the food webs in the paddy and maize fields were stressed, because the majority of sites were in quadrat D (Fig. 4), which indicated stressed disturbance and a degraded food web condition in paddy and maize fields. Faunal profiles showed that the EI decreased, on the whole, from upper soil layers to deeper soil layers under different land use types, with an exception of the paddy field.

At different depths, a total decrease trend was found in the value of BI among land use types (Fig. 5), while maize field > paddy field > fallow field > woodland. The lowest value of BI in woodland was found from 0–5 to 80–100 cm depth in comparison to other treatments.

Discussion

A gradual decrease trend in the number of total nematodes with depth under different land use regimes showed that stratification of the biological activity within the soil profile. The similar trends were found under the shortgrass prairie down to 150 cm depth (Gould et al., 1979) and beneath a stand of 400 stems ha\(^{-1}\) Pinus radiata in a grazed pasture down to 80 cm (Yeates et al., 2000). Sohlenius and Sandor (1987) found the peak number of total nematodes occurred at 20–30 cm under grass and barley fields down to 50 cm depth. Yeates and Stannard (1983) found that the total nematode population in 0–90 cm soil layers under cocksfoot swards declined consistently with depth, whereas the population below ryegrass pasture had a secondary peak at 40–50 cm depth. The differences detected in vertical distribution above could be related to factors of soil type (Yeates, 1980), rooting pattern (Pen-Mouratov et al., 2004), anthropogenic disturbance (Yeates and King, 1997), sampling season (Liang et al., 1999) and so on. The numbers of total nematodes, bacterivores, fungivores, plant parasites and omnivores-predators in the paddy field were found to be significantly lower in comparison to the other three land use types. This study indicated that nematode communities in the paddy field were characterized by low density and low genera diversity (Coyne et al., 1999). Waterlogged soils may become oxygen deficient and stimulate sulfatereducing bacteria to produce sulfur compounds toxic to nematodes (Porazinska et al., 1999). Low density of nematodes found in the paddy field after harvest, reflected subsequent effects suppressed by moisture during the growing season of the paddy field. No significant differences in the number of total nematodes between maize field, fallow field and woodland at all depths from 0–5 to 120–150 cm, indicated that the maize field exerted no significant effects on the number of total nematodes in comparison to fallow field and woodland. In our study, the contents of soil organic carbon, total N and alkali N along soil profiles were significantly higher in woodland than in maize, fallow, and paddy fields, while there was no significant difference between maize and fallow fields, with an exception of the surface soil (Zhang et al., 2004b). The order of the average content of Olsen-P along soil profiles was fallow field > woodland > maize field > paddy field (Zhang et al., 2004a). Different status of nutrients along profiles between treatments did not result in difference of the number of total nematodes between maize field, fallow field and woodland at all depths. The great majority of soil nematodes were present in 0–30 cm soil layers under four land use types. Gould et al. (1979) found that soil nematodes were present at 150 cm and over 80% of them occurred in the depth of 20 cm under the shortgrass prairie. Fig. 1B, based on individuals per unit volume calculated from bulk density exhibited the similar trend with Fig. 1A, this suggested that the soil nematodes expressed with individuals 100 g\(^{-1}\) dry
soil had a consistent result with individuals 100 cm$^{-3}$ dry soil.

In this study, bacterivores were the most abundant group in paddy field. The higher population of bacterivores indicated that the bacterial-based energy channel contributed relatively more to organic matter decomposition in the paddy field (Mikola and Sulkava, 2001). The number of fungi-vores at the depths of 0–5 and 5–10 cm was higher in the maize field than in the other land use types. This suggested a fungal-decomposer-dominated food web at 0–10 cm depths in the maize field. The number of fungivores was low in the paddy field at all depths, less than 3 individuals 100 g$^{-1}$ dry soil. This was likely to reflect the relationships between fungivores and food resources (Fu et al., 2000). In the paddy field, the number of fungi is low under anaerobic condition, because fungi favours aerobic condition. Wardle and Yeates (1993) concluded that microbivorous nematodes were limited by resource availability. A total decrease trend in the number of fungivores was found from 0–5 to 120–150 cm under each land use type. Plant parasites were found to be the most abundant group in the maize field, fallow field and woodland. Yeates et al. (2000) found low population of plant

![Faunal profiles under different land use types.](image)

**Figure 4.** Faunal profiles under different land use types. Soil depths: (1) 0–5 cm, (2) 5–10 cm, (3) 10–20 cm, (4) 20–30 cm, (5) 30–40 cm, (6) 40–60 cm, (7) 60–80 cm, (8) 80–100 cm, (9) 100–120 cm, and (10) 120–150 cm.

![Changes in basal index along soil profiles under different land use types.](image)

**Figure 5.** Changes in basal index along soil profiles under different land use types.
parasites at 10–80 cm depth beneath a stand of 400 stems ha\(^{-1}\) \textit{P. radiata} in a grazed pasture. Most publications indicate that plant parasites could be controlled by vegetation types and closely related to rooting patterns (Yeates, 1980; Manlay et al., 2000). The decrease trend in the number of plant parasites was found with depth under different land use types. The relatively higher population of the omnivores-predators in the fallow field and woodland at the depths of 0–5, 5–10, 10–20 cm reflected the importance of omnivores-predators in the two ecosystems. This result was in agreement with that reported by López-Fando and Bello (1995). In the fallow field and woodland, the omnivores-predators have a wide effect on other trophic groups by controlling the composition of soil microfauna as well as the pool of readily available organic sources. Ferris and McKenry (1976) observed omnivores and microbivores in a California vineyard, being concentrated near the soil surface, were similarly distributed, whereas plant parasites were spread to greater depths down to 120 cm. Previous studies owed the low abundance and diversity of omnivores-predators to agricultural practices (Freckman and Ettema, 1993). Omnivores-predators may seem to be more appropriate in defining soil ecosystem status (Porazinska et al., 1999).

On the whole, the number of total nematodes and trophic groups exhibited positive correlation with the contents of TOC, total N, alkali N under the four land use types. Yeates (1980) found correlation between nematode abundance and soil carbon, readily available soil phosphorus when examining the vertical distribution of nematodes in 0–30 cm soil beneath grazed pastures. The correlation between nematode and available phosphorus was not found in our study, which was likely to be due to different soil types (Yeates, 1980). Wall et al. (2002) reported that nematode abundance, plant parasites and omnivores were positively correlated with soil organic matter. This result was in agreement with our study.

It is generally accepted that undisturbed systems have more diverse communities of soil organisms (Kandji et al., 2001). This reflected a higher diversity derived from greater basal resource inputs. woodland has more variation in vegetation, and thus in belowground input (Ettema and Yeates, 2003). Community-level patterns were apparent with regard to the nematode richness data, and those plots with more groundcover vegetation often supported the most diverse assemblages of nematodes, possibly as a result of greater heterogeneity of resources added through the return of residues and root-exudates. This result was generally in agreement with other studies (Bouwman and Arts, 2000; Wardle et al., 2001). In agroecosystems the return of surface plant debris is small due to low litter fall and the export of agricultural products. Generally those treatments with low levels of ground-layer plants present also supported the lowest nematode richness. The paddy and maize fields had lower number of parasitic genera, which might be associated with the death of the crop rooting after harvest. Manlay et al. (2000) concluded that course roots of trees clearly played a key role in maintaining nematode diversity. The number of genera reached maximum at 5–10 cm depth under different land use types. This was likely to be due to suitable microclimate and higher organic matter. Upper 0–5 cm soil layer is easy to be disturbed by exoteric environment (Ferris and McKenry, 1974).

The faunal profiles showed that soil food webs in the fallow field and woodland were structured, and those in the paddy and maize fields were stressed. This study supported the conclusions that food webs from annual cropping systems usually map in the left side of the faunal profile while those from undisturbed natural systems usually map on the right (Ferris et al., 2001). Higher SI values of the fallow field and woodland resulted from the presence of omnivores-predators, which suggested a food web with more trophic linkages in these ecosystems (Ferris and Matute, 2003). Environmental stability and homeostasis of the fallow field and woodland resulted in the highest levels of community structure, indicating a well-regulated, healthy ecosystem. Some sites of the fallow field and woodland were in quadrant D, and some sites of the paddy and maize fields were in quadrant C, which were located in deeper soil layers. This result indicated that the faunal analysis provided a useful tool for diagnostic interpretation of the condition of upper soil layers. Woodland exhibited lower value of BI from 0–5 to 80–100 cm depth, indicating a healthy ecosystem. A high BI value in the paddy and maize fields could indicate poor ecosystem health (Berkelmans et al., 2003). Based on the above discussion, both BI and SI might be regarded as the potential indicators for assessing ecosystem health.

Changes in soil environmental surroundings resulted from land use regimes, could increase diversity of nematode communities by creating niches. Plants varied considerably in rooting patterns and depths, leading to a stratified return of debris, which altered the changes in a variety of biological, physical and chemical variables. At the same time long-term anthropogenic disturbances such as tillage, especially flooding in the paddy
field, exerted great effects on soil nematode communities.

Our study showed that spatial patterning was an important property and provided clear evidence that different land use types differed tremendously in terms of their effects on the nematode communities. In this paper, temporal factors were not considered. The timing of the sampling might be responsible for some consistencies and discrepancies. Therefore further studies are needed.

Acknowledgements

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