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RESEARCH ARTICLE

Effects of vegetation coverage on the spatial distribution of soil nematode trophic groups

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Abstract The spatial variability of total soil nematodes and trophic groups in bare and fallow plots in Shenyang Experimental Station of Ecology, Chinese Academy of Sciences was examined using geostatistics combined with classic statistics. Results showed that the soil pH value had a negative effect on plant-parasites in both bare and fallow plots; the mean number of total nematodes was significantly higher in fallow plots than in bare plots, which was 1485.3 and 464.0 individuals per 100 g dry soil in fallow and bare plots, respectively; the nugget (C_0)/sill (C_0+C) ratio of total nematodes, plant-parasites and bacterivores were lower in fallow plots (27.3%–45.6%) than in bare plots (49.5%–100%); the spatial distribution of total nematodes and trophic groups was found to be different between fallow and bare plots, which indicated that vegetation coverage had an effect on soil nematodes.

Keywords vegetation coverage, soil nematode, trophic group, spatial distribution, geostatistics

1 Introduction

Recent studies indicated that soil nematodes were able to respond to the disturbed ecosystems, and they were regarded as sensitive bioindicators to the changes in ecosystems (Bongers, 1990; Neher et al., 1995). The spatial heterogeneity of nematode trophic interactions within soil food webs has become a determinative factor in the dynamics of soil nutrients (Moore and De Ruiter, 1991), and had an important effect on nutrient cycling and energy flow in ecosystems. Spatial dependence is particularly important in the analysis of spatially varying organism distributions and environmental variables, yet many classic statistical measures tend to ignore it (Rossi et al., 1992). Geostatistics has been proven to be a powerful tool for detecting and quantifying heterogeneity of soil nutrients (Jiang et al., 2003; Jiang et al., 2005a) and spatial distribution of soil biota (Wallace and Hawkins, 1994; Liang et al., 2005). Many researchers have studied the distribution patterns of soil nematodes (Wallace and Hawkins, 1994; Liang et al., 2005), and mainly focused on the spatial distribution of nematodes in arable soils (Ettema et al., 1998; Liang et al., 2003). There is no information about the differences in nematode spatial distribution between the vegetation coverage and bare lands. Vegetation coverage had an important effect on the growth and development of soil microbes and nematodes (Ou et al., 2005). Many studie indicated that plant-parasitic nematodes were affected by plant types (de Goede and Bongers, 1994; McSorley, 1997), and soil nematode abundance was significantly correlated with the distribution of plant roots (Wasilewska, 1997; Manlay et al., 2000). Therefore, the objectives of this research were to examine the spatial variability of total soil nematodes and trophic groups in bare and fallow plots in Shenyang Experimental Station of Ecology, Chinese Academy of Sciences using geostatistics combined with classic statistics methods, and to provide a scientific base for managing healthy soil ecosystem.

2 Materials and methods

2.1 Study 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 in the lower reaches of the Liao River plain in Northeast China. The station is located in the continental temperate monsoon zone. The annual mean temperature is 7.0°C to 8.0°C, annual precipitation averages from 650 to 700 mm, and annual non-frost period is 147 to 164 days. The soil is an

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aquic brown soil (silty loam Hapli-Udic Cambisols in Chinese soil taxonomy). The experimental field has fallowed since 1994. The adjacent plots were set up after burning in 2002. These were marked on regular square grids with 2-m spacing between the sampling points (Fig. 1). One (fallow plot) is on a natural vegetative cover, dominated by *Artemisia lavandulaefolia*, *Cephalanoplos segetum*, *Chenopodium serotinum*, *Metaplexis japonica* and *Conyza Canadensis*. The biomass of the vegetation covered on fallow land is 0.59 kg/m^2. Another is a bare plot where no plants grow.

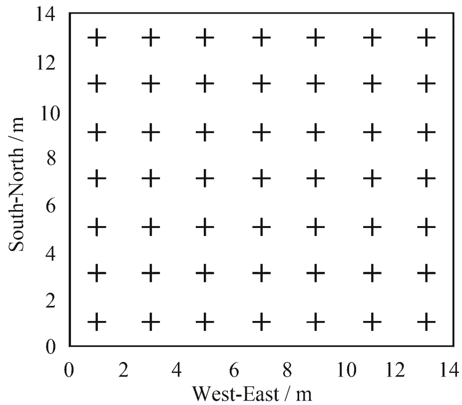

Fig. 1 Spatial location of sample points in bare and fallow lands

2.2 Sampling and analytical methods

Soil samples were collected from the depth of 0–20 cm in the two plots using a 2.5-cm diameter corer on 18 November 2004. Each plot included 49 sampling points, and each soil sample comprised five subsamples. All samples were stored in individual plastic bags, and immediately transferred to the laboratory.

After being air-dried, each sample passed through a 2-mm screen to remove roots and other debris for chemical analysis. The following analyses were conducted on each of the samples: soil total nitrogen (TN) was measured with Kjeldahl method, and total organic carbon (TOC) were determined with the dry combustion method using a Shimadzu TOC-5000A Total C analyzer.

Nematodes were extracted from 100 g (fresh weight) of soil from each sample using sugar flotation and centrifugation (Ingham, 1994; Liang et al., 2001b), killed by heat and fixed in 4% formaldehyde. All nematodes in each sample were counted and expressed as per 100 g dry soil according to the soil moisture (Liang et al., 2001a). The classification of trophic groups was assigned to: 1) bacterivores, 2) fungivores, 3) plant-parasites, and 4) omnivores-predators on the basis of the known feeding habits or stoma and esophageal morphology (Yeates et al., 1993).

Classical statistical parameters, i.e. mean, standard deviation, coefficient of variation, minimum and maximum, were calculated using Statistics Package for Social Science (SPSS) 10.0 software (SPSS Inc., Chicago). Isotropic semivariances of data were calculated using GS+ geostatistical software (Gamma Design Software 2000). Maps of total nematodes and trophic groups were computed subsequently for the two plots using block kriging at a block size of 3 m (Rossi et al., 1992; Jiang et al., 2005b).

3 Results

3.1 Descriptive statistics for total nematodes and trophic groups

The results of the descriptive statistics for total nematodes and trophic groups in the bare and fallow plots are showed in Table 1. Significant differences in the mean numbers of total nematodes and the four trophic groups were found from the mean values, and the numbers were significantly higher in the fallow plot than in the bare plot ($P < 0.01$). The coefficients of variation of soil nematodes were higher in the fallow plot than in the bare plot, except omnivores-predators.

According to the mean values of soil nematodes in Table 1, the relative abundances of plant-parasites, bacterivores, fungivores and ominvores-predators in the fallow plot were 73.0%, 22.4%, 1.9% and 2.7%, respectively; while those in the bare plot were 57.1%, 35.9%, 5.3% and 1.6%, respectively. The relative abundance of plant-parasites was significantly higher in the fallow plot than in the bare plot.

3.2 Spatial distribution of total nematodes and trophic groups

Table 2 shows the semivariogram models for the variables over the two plots. In the bare plot, the best-fitted models for total nematodes and omnivores-predators were linear; and those for plant-parasites, bacterivores and fungivores were exponential. In the fallow plot, the best-fitted models for total nematodes and plant-parasites were spherical; and those for bacterivores exponential, fungivores and omnivores-predators were linear (Table 2). The coefficients of determination (R^2) of all variables were significantly different ($P < 0.01$), except those of plant-parasites and fungivores in the bare plot ($P < 0.05$). These indicated that the models fitted the experimental semivariogram data well and could reflect the spatial distribution of total nematodes and trophic groups in the bare and fallow plots.

The values of sill ($C_0 + C$) for soil nematodes were lower in the bare plot than in the fallow plot (Table 2), which indicated that the intrinsic variance in the bare plot was lower. The ratio of C_0 to $C_0 + C$ reflects the proportion of random variance to total sample variance, and $C_0/(C_0 + C)$ of total nematodes, plant-parasites and bacterivores was higher in the bare plot than in the fallow plot. Total nematodes, plant-parasites and bacterivores in the fallow plot had a lower value of $C_0/(C_0 + C)$ (27.3%–45.6%), which indicated that the influence of extrinsic factors on total nematodes, plant-parasites and bacterivores had been playing an important role. The values of $C_0/(C_0 + C)$ for total nematodes and omnivores-predators in the bare plot, and fungivores and omnivores-predators in the fallow plot were 100% (pure

Table 1 Results of the number of total nematodes and trophic groups (individuals per 100 g dry soil) for descriptive statistics

Treatment	Item	Mean ± S.D	CV /%	Median	Minimum	Maximum	Skewness	Kurtosis
Bare plot	TNEM*	464.0 ± 150.7	32.49	450.10	160	758	0.140	–0.202
	PP	265.0 ± 142.2	53.65	251.43	45	655	0.574	0.017
	BF	166.8 ± 91.8	55.05	155.57	7	482	0.966	1.609
	FF	24.6 ± 23.6	95.90	18.96	0	98	1.493	2.006
	OP	7.6 ± 10.2	133.65	3.82	0	38	1.384	1.163
Fallow plot	TNEM	1485.3 ± 794.1	53.47	1301.65	519	5233	2.345	9.247
	PP	1084.6 ± 777.3	71.66	1038.45	165	5128	3.017	14.533
	BF	332.0 ± 223.4	67.29	278.09	35	1130	1.682	3.487
	FF	28.7 ± 39.5	137.95	16.04	0	176	2.292	5.187
	OP	39.9 ± 42.9	107.38	24.41	0	176	1.670	2.520

Note: * TNEM: total nematodes; PP: plant-parasites; BF: bacterivores; FF: fungivores; OP: omnivore/predators. The same below.

Table 2 Parameters of the best-fitted semivariogram model for isotropic variogram

Treatment	Item	Model	Nugget C_0	Sill C_0+C	$C_0/(C_0+C)$ /%	Range A, /m	Model R^2	*RSS*	*F* value
Bare plot	TNEM	Linear	23552	23552	100.0	10.55	0.351	1.849E+7	4.65**
	PP	Exponential	20030	40070	50.0	30.99	0.253	3.519E+6	2.91*
	BF	Exponential	6820	13776	49.5	27.02	0.531	1.440E+6	9.74**
	FF	Exponential	474	948	50.0	30.99	0.251	38,244	2.88*
	OP	Linear	108	108	100.0	10.55	0.673	650	17.70**
Fallow plot	TNEM	Spherical	351000	1021400	34.4	30.99	0.889	4.937E+9	68.88**
	PP	Spherical	289000	1058000	27.3	30.99	0.846	9.492E+9	47.24**
	BF	Exponential	40900	89630	45.6	30.99	0.417	9.687E+7	6.15**
	FF	Linear	1601	1601	100.0	10.55	0.330	31,225	4.24**
	OP	Linear	1938	1938	100.0	10.55	0.647	93,711	15.76**

Note: *,** significant at $P = 0.05$ and 0.01 levels, $F_{0.05} = 2.41$; $F_{0.01} = 3.42$.

nugget effect), which reflected that their spatial variances were mainly caused by random factors.

The range (A) indicates the influential distance of variables. The range of spatial correlation for total nematodes and trophic groups in the bare and fallow plots varied from 10.55 to 30.99 m. The range values of total nematodes and trophic groups were lower (or equal) in the bare plot than in the fallow plot, except fungivores in the bare plot (Table 2). These results indicated that the spatial heterogeneity of soil nematodes in the fallow plot existed within a longer distance, while that in the bare plot within a shorter distance.

The maps obtained by kriging for soil nematodes in the bare and fallow plots are shown in Fig. 2. The number of total nematodes and trophic groups was higher in the fallow plot than in the bare plot, which indicated that there were more nematodes in the surface soil covered by vegetation. In addition, there was a greater spatial variability of soil nematodes in the bare and fallow plots. The number of bacterivores was higher in the western area. In the fallow plot, the spatial distribution of total nematodes exhibited a similar trend with that of plant-parasites, and the numbers of total nematodes and plant-parasites were higher in the northeast corner.

3.3 Correlations between soil physicochemical properties and nematodes

Significant differences in soil pH, cation exchange capcity (CEC), TOC and TN were found between the fallow and bare plots ($P < 0.01$). The values of them were higher in the fallow plot than in the bare plot, except those of CEC. Soil pH was negatively correlated with the number of plant-parasites in the bare plot ($r = -0.337$, $P < 0.05$) and in the fallow plot ($r = -0.302$, $P < 0.05$). No significant correlations were observed between soil nematodes and CEC, TOC and TN.

4 Discussion

Connell and Slatyer (1977) pointed out that vegetative structure influenced population densities of soil fauna through changing microclimate and soil nutrients, and the habitat diversification of vegetation had deep effects on diversity of soil faunal communities. The numbers of total nematodes and trophic groups were significantly higher in the fallow plot than in the bare plot in this study. Some studies indicated that fallow could effectively restore farmland ecosystems (Prach and Pyšek, 2001), improve soil fertility (Cadet and Floret, 1999), establish soil biological communities and increase biological activities and biodiversity. Plant-parasites are fed by plant roots, and their numbers and relative abundances were significantly higher in the fallow plot than in the bare plot, which reflected that vegetative cover was favorable for increasing the number of soil nematodes to some extent. Rehabilitation of natural vegetation in fallow treatments formed a great deal of litter after no artificial disturbance, such as plowing (Szott et al., 1994), and increased the accumulation of soil organic matters, which improve the reproduction and development of soil

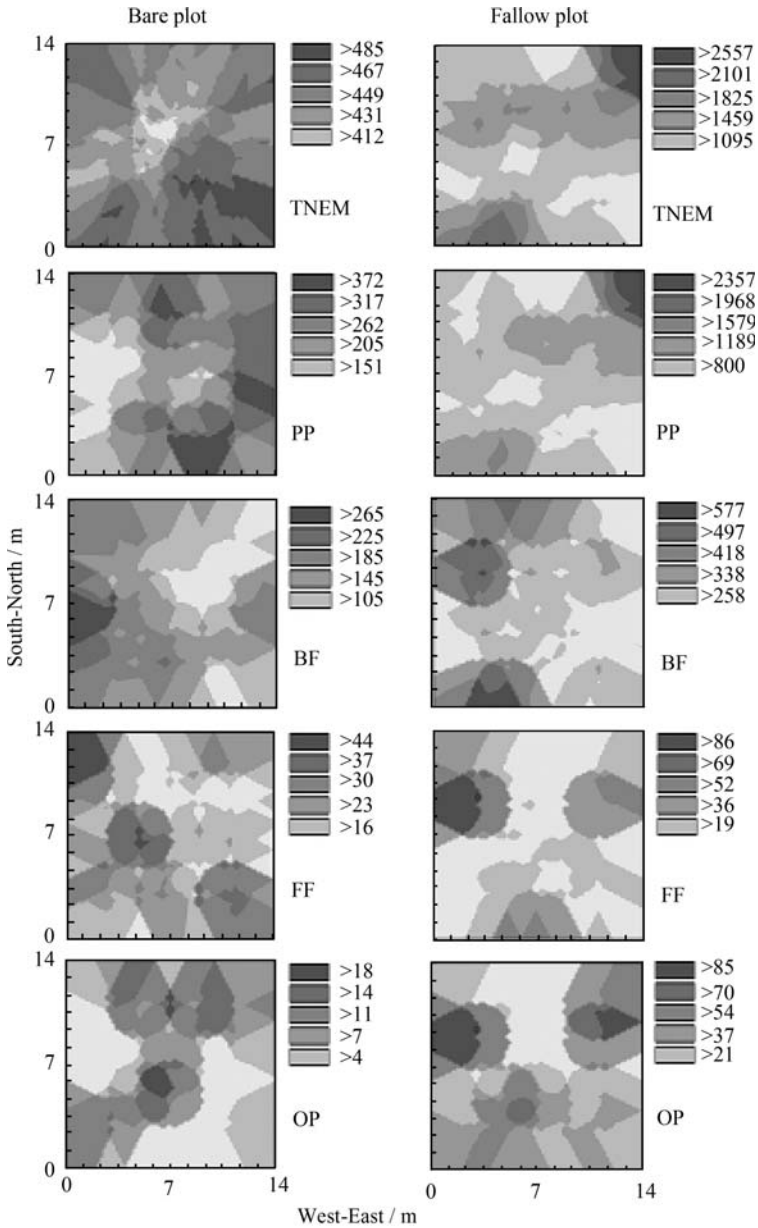

Fig. 2 Spatial distribution of soil nematodes in the bare and fallow plots (individuals per 100 g dry soil)

microorganisms. Omnivores-predators not only feed soil microorganisms, but also other nematode trophic groups. Rich food resources increase the numbers of bacterivores and omnivores-predators.

The spatial variability of soil nematodes in the fallow plot was mainly influenced by the structural factors, and exhibited a stronger spatial autocorrelation. While the spatial heterogeneity of soil nematodes in the bare plot was controlled by random factors, i.e. rainfall, light and winding (Bloemers et al., 1997; Venette and Ferris, 1997), which resulted in a weaker spatial autocorrelation.

The semivariogram models were best-fitted according to the coefficients of determination (R^2) by F test. The coefficients of variance (CV) of soil nematodes (except omnivores-predators) were lower in the bare plot than in the fallow plot, which indicated that there was a higher heterogeneity of total nematodes, plant-parasites, bacterivores and fungivores in the fallow plot. The characteristics of the soil community structure affect the spatial and temporal heterogeneity of soil organic layers, which formed a greater spatial variability of soil nematodes in the fallow plot (Beare et al., 1995). The fallow plot had a stronger spatial and temporal heterogeneity of weed distribution in the present study, and a higher spatial variability of soil nutrients was found in the fallow plot due to the effects of vegetative cover.

Ettema et al. (1998) and Liang et al. (2003) studied the spatial distribution patterns of soil nematodes in a Georgia riparian wetland (USA) and Hailun Agroecological Station of the Chinese Academy of Sciences (47°26′N, 126°38′E), respectively. The results showed that no significant correlations were observed between the total nematodes, trophic groups and soil physicochemical properties. In our study, significant differences were only found between soil pH and the numbers of plant-parasites in the bare and fallow plots, which were consistent with those reported by Kandji et al. (2001). The values of soil pH, total organic carbon and total nitrogen were significantly lower in the bare plot than in the fallow plot, except CEC. The reason was perhaps due to soil nutrient exhaustion and loss that decreased soil fertility (Rhoades, 1983). The growth of plant roots and their exudates, soil faunal activities could improve soil physicochemical properties (Abbadie et al., 1992). In addition, the number of free-living nematodes (bacterivores, fungivores and omnivores-predators) was significantly lower in the bare plot than in the fallow plot, which indicated the decline of soil fertility in the bare plot (Bongers and Bongers, 1998).

The number of bacterivores in the bare plot was higher in the west and lower in east, while that of total nematodes and plant-parasites in the fallow plot was higher in the northeast corner. Ou et al. (2005) investigated that there were trees in the west of the bare plot and in the northeast of the fallow plot, the tree roots, their exudates and shadow canopies could affect the spatial distribution of soil nematodes.

In conclusion, significant differences in the spatial distribution patterns of total nematodes and trophic groups were observed in the bare and fallow plots. Similar distribution patterns were observed between total nematodes and plant-parasites in the fallow plot. These results indicated that vegetative cover had important effects on the spatial distribution of soil nematodes.

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