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RESEARCH ARTICLE

Effect of slow-release urea on soil nematode community structure in a Chinese soybean field

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Abstract The effect of slow-release urea on soil nematode community structure was investigated in a soybean field in northeast China. Three treatments, no urea (CK), conventional urea (U) and slow-release urea (SRU), were arranged in a completely random design. The results show that the abundance of total nematodes was significantly higher in SRU than in CK and U. Significant differences in the abundance of bacterivores with colonizer-persister (cp) values 2–3, fungivores with cp 2 and herbivores with cp 3 were found among different treatments. Forty-one genera were identified, of which *Acrobeloides*, *Aphelenchus* and *Heterodera* were dominant. Soil nematode guilds and genera exhibited different responses to slow-release urea. The most trophic groups and genera had greater abundances in SRU than in CK and U. Slow-release urea had a positive effect on soil nematode community structure.

Keywords soil nematodes, community structure, nematode guilds, slow-release urea, soybean field

1 Introduction

Urea, as a kind of nitrogen fertilizer, is commonly and largely used worldwide and accounts for about 50% of total nitrogen fertilizers. In China, the consumption of urea is 40% of the worldwide consumption (Zhou et al., 2003). Urea can be rapidly hydrolyzed to NH_3 and CO_2 by soil urease after being applied to soil, followed by NO_3^- formation through nitrification (Gioacchini et al., 2002). Therefore, ammonia loss and nitrate leaching are environmental concerns in regions where urea is applied (Liang et al., 2005). High consumption and low efficiency during the process of urea use not only results in resource waste but also deteriorates the eco-environment. In order to improve urea-N recovery and reduce its loss, a new type of slow-release urea (urea incorporated with a liquid urease inhibitor) has been manufactured by the Jinxi Natural Gas Chemicals Co., Ltd. (China). This slow-release urea can increase the efficiency of applied urea-N (Liang et al., 2005).

Although the effect of urease inhibitors on reducing urea N loss has been assessed in field trials (Gioacchini et al., 2002; Zhou et al., 2003), little attention has been paid to their effects on soil nematode communities (Liang et al., 2005; Hua et al., 2006). Soil nematodes such as bacterial- and fungal-feeding nematodes have positive roles in the process of nutrient cycling and plant productivity. They can increase the rate of organic matter mineralization and exert a regulatory influence on the composition, activity and productivity of soil microorganisms (Ingham et al., 1985; Bardgett et al., 1999). Nematode fauna composition has emerged as useful bioindicators in assessing soil ecosystem status and function because soil nematodes are ubiquitous and easy to sample and they can be classified into feeding groups or functional guilds (Yeates and Bongers, 1999; Ekschmitt et al., 2001; Neher, 2001; Liang et al., 2005; Liang et al., 2007a and 2007b; Okada and Harada, 2007; Li et al., 2008; Liang et al., 2008).

Previously, studies of the effect of fertilizers on soil nematode communities were mainly focused on conventional chemical fertilizers (Wang et al., 2006; Gruzdeva et al., 2007; Li et al., 2007; Okada and Harada, 2007; Tsiafouli et al., 2007; Liang et al., 2008), while there were only a few devoted to the effect of slow-release urea fertilizer on soil nematode communities. We hypothesize that (1) soil nematodes are good bioindicators that can reflect the differences between conventional urea and slow-release urea; (2) slow-release urea fertilization has a positive effect on nematode communities compared with conventional urea. The objectives of this study were to compare the impact of conventional and slow-release urea on soil nematode community structure in a soybean

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(*Glycine max*) field in northeast China and assess the biological effect of slow-release urea by nematode faunal analysis.

2 Materials and methods

The study was conducted at a soybean experimental site of the Heilongjiang August First Land Reclamation University (46°39′ N, 125°16′ E) in northeast China. Located in the continental monsoon zone, the area has a dry, cold winter and a warm, wet summer. The mean annual temperature is 4.4ºC. The mean annual precipitation is 428 mm and the non-frost period is about 146 days. The test soil is classified as a Usti-Sandic Primosol (Chinese soil taxonomy), with 19.06 $g \cdot kg^{-1}$ total C, 1.55 $g \cdot kg^{-1}$ total N, pH (H_2O) 8.4, 75.1% sand, 18.8% silt and 5.1% clay at 0–20 cm depth.

Sixteen experimental plots, 10.0 m × 4.2 m each, were sown with soybean seeds on May 25, 2007 in a conventional tillage system. Three treatments, *i.e.* control (CK, no urea), conventional urea (U, 53.1 kg $N \cdot ha^{-1}$) and slow-release urea (SRU, 53.1 kg $N \cdot ha^{-1}$), were arranged in a completely randomized design with four replications. Before the sowing of soybean seeds, U plots were treated with urea and SRU plots with slow-release urea, while each plot received 86.4 kg $P \cdot ha^{-1}$ from superphosphate, and 42.0 kg $K \cdot ha^{-1}$ from potassium chloride.

Soil samples were collected from each plot at 0–20 cm depth at three important growth periods of soybean: June 14 (seedling stage), July 26 (flowering stage) and October 3 (ripening stage). Each sample, comprised of five soil cores (2.5 cm in diameter), was placed in a separate plastic bag and then immediately stored in a 4°C cold room. Soil NO_3^-–N and NH_4^+–N across all the sampling stages were determined by extraction with 2 M KCl, steam distillation and titration (Mulvaney, 1996).

Nematodes were extracted from 100 g (fresh weight) of soil from each sample using the modified cotton wool filter method (Liang et al., 2008). The abundance of nematodes was expressed per 100 g dry weight soil. Nematodes were identified to the genus level using an inverted compound microscope. The soil nematodes identified were classified into five life-history groups (the colonizer-persister (cp) values 1 to 5) and five trophic groups (Bongers, 1990; Yeates et al., 1993). The cp values for taxa were adopted from Bongers (1990) and Bongers and Bongers (1998). The classification of trophic groups was assigned to bacterivore (Ba), fungivore (Fu), omnivore (Om), carnivore (predator) (Ca) and herbivore (plant parasite) (H), based on known feeding habitats or stoma (Yeates et al., 1993; Ferris and Matute, 2003).

All statistical analyses were performed using the SPSS software package. All data on the abundance of nematode assemblages were ln $(x+1)$ transformed and proportions were transformed as the arcsine of square root before the analysis in order to achieve normality of the data. Actual data values were presented in tables and figures. Significant differences in soil inorganic nitrogen and soil nematode data were calculated using a two-way ANOVA with treatments and growth periods as independent variables; significant differences of different treatments at each growth stage were calculated using one-way ANOVA. For all tests, statistically significant differences were assigned to $P < 0.05$. Canonical correspondence analysis (CCA) was performed to explore the soil nematode genera and soil inorganic nitrogen in relation to fertilizer treatment. A direct gradient procedure was performed with CANOCO software (Version 4.5). Fertilizer treatments were treated as nominal (0, 1) environmental variables. A Monte Carlo permutation option was employed to determine the significance of first axis.

3 Results

3.1 Soil inorganic nitrogen

The contents of soil inorganic nitrogen under different treatments during the soybean growing season are shown in Table 1. At the seedling stage, the contents of NO_3^-–N were significantly lower in CK than in U and SRU ($P < 0.05$), those of NH_4^+–N were significantly higher in U than in CK and SRU ($P < 0.05$), and those of total inorganic nitrogen (TIN) were significantly different among the three treatments ($P < 0.01$). No significant differences among different treatments were observed at the flowering stage. At the ripening stage, significant differences in the concentrations of NH_4^+–N were found among different treatments ($P < 0.01$). The analysis results of two-way

Table 1 Soil inorganic nitrogen under different treatments during soybean growing season

sampling stage	CK/$mg \cdot kg^{-1}$	U/$mg \cdot kg^{-1}$	SRU/$mg \cdot kg^{-1}$
seedling			
NO_3^-–N	2.37 ± 0.03	3.06 ± 0.44	3.15 ± 0.19
NH_4^+–N	1.12 ± 0.09	2.58 ± 0.52	1.34 ± 0.44
TIN	3.48 ± 0.13	5.63 ± 0.08	4.49 ± 0.33
flowering			
NO_3^-–N	2.53 ± 0.61	3.12 ± 0.83	3.88 ± 1.51
NH_4^+–N	1.31 ± 0.01	1.66 ± 0.75	1.33 ± 0.11
TIN	3.84 ± 0.61	4.77 ± 0.77	5.21 ± 1.46
ripening			
NO_3^-–N	2.34 ± 0.51	2.53 ± 0.46	3.10 ± 0.21
NH_4^+–N	1.00 ± 0.27	1.85 ± 0.26	1.75 ± 0.13
TIN	3.93 ± 0.76	4.37 ± 0.60	4.85 ± 0.31

CK: no urea; U: conventional urea; SRU: slow-release urea; TIN: total inorganic nitrogen (NO_3^-–N + NH_4^+–N).

ANOVA shows that significant treatment effects at the concentrations of NH_4^+–N and TIN were found ($P<0.05$). Canonical correspondence analysis of the association of soil inorganic nitrogen (NO_3^-–N, NH_4^+–N and TIN) and fertilizer treatments (CK, U and SRU) is shown in Figure 1. During the soybean growing season, SRU was characterized by a relatively high NO_3^-–N and U treatment was characterized by a relatively high NH_4^+–N.

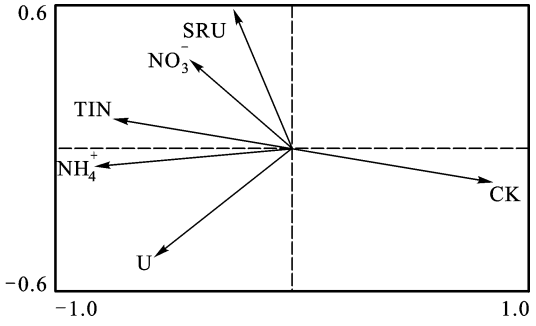

Fig. 1 Canonical correspondence analysis scatter-plot of soil inorganic nitrogen (NO_3^-–N, NH_4^+–N and TIN) and fertilizer treatments (CK, U and SRU) with 41 soil nematode genera

3.2 Total nematodes

The number of total nematodes under different treatments during soybean growing season ranged from 88 to 340 individuals per 100 g dry soil (Fig. 2). Two-way ANOVA shows that the main effects of treatments and growth stages on total nematodes were significant ($P<0.01$), whereas the abundance of total nematodes was significantly higher in SRU than in CK and U and at the ripening stage than at the seedling and flowering stages.

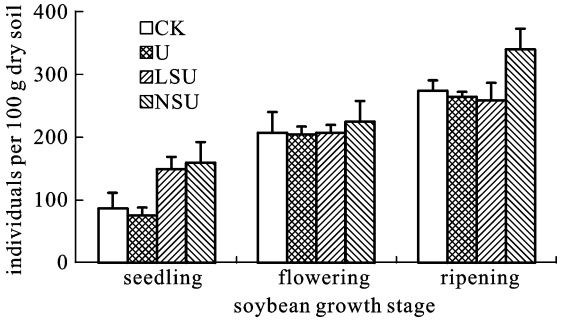

Fig. 2 Abundance of total nematodes under different treatments during soybean growing season (Error bars represent the standard error)

3.3 Nematode genera

Forty-one genera of nematodes were identified, of which *Acrobeloides*, *Aphelenchus* and *Heterodera* were dominant (their relative abundance > 10%) (Table 2). The main effects of treatments and growth stages on the abundance of *Acrobeloides* and *Aphelenchus* were all significant, whereas only the growth stage effect on the abundance of *Heterodera* was significant ($P<0.01$). The abundance of *Acrobeloides*, *Aphelenchus* and *Heterodera* were lower at the seedling stage than at flowering and ripening stages, and those of *Acrobeloides* and *Aphelenchus* were significantly higher in SRU than in CK and U.

CCA bi-plots of soil nematode genera and environmental variables during soybean growing season are shown in Figure 3. Nematode composition varied among different fertilizer treatments and different growth stages. In the CCA ordination diagram of genera and environmental variables, a great number of genera occurred near the origin of the axes. These genera can be considered as habitat generalists, while those occurring far from the origin are habitat specialists. For example, *Acrobeloides*, which belonged to a dominant genus, was near the origin of the axes and could be considered as a generalist and survived in the three habitats. *Alaimus* and *Tylenchorhynchus* at the seedling stage far from the origin of the axes only survived in U and SRU, respectively. At the flowering stage, *Cervidellus* only survived in CK, *Wilsonema* in U, and *Alaimus*, *Psilenchus* and *Longidorus* in SRU. At the ripening stage, *Longidorus*, *Malenchus*, *Psilenchus*, *Rhabdolaimus* and *Dorylaimoides* only existed in CK, and *Mesodorylaimus* in U. Eigenvalues for the first axis were 0.101, 0.080 and 0.091 for the seedling, flowering and ripening stages, respectively (Table 3). The eigenvalues for the first axis at three growth stages were all significant. The first axis explained 19.4%, 19.4% and 23.5% of the cumulative variance of the genera data at the three stages, respectively. The genera-environment correlations for the first axis were all more than 0.9.

3.4 Nematode guilds

The abundance of soil nematode guilds under different treatments across the sampling periods is shown in Table 4. At the seedling stage, omnivores with cp 4 were significantly higher in SRU than in CK and U ($P<0.01$). At the flowering stage, bacterivores with cp 4 and herbivores with cp 5 were also significantly higher in SRU than in CK and U ($P<0.05$ and $P<0.01$, respectively). At the ripening stage, bacterivores with cp 2 were significantly lower in U than in SRU.

The main effects of treatments on bacterivores with cp 2–3, fungivores with cp 2 and herbivores with cp 3 were significant. Also the main effects of growth stages on bacterivores with cp 1–3, fungivores with cp 2, omnivore with cp 4, carnivore with cp 5 and herbivores with cp 2–3 were all significant. However, the two-way interactions of growth stage × treatment were significantly different ($P<0.05$) in the abundance of bacterivores with cp 2–3 and herbivores with cp 5.

Table 2 Mean relative abundance (%) of nematode genera under different treatments during soybean growing season

guild*/genus	genus abbreviation	seedling stage			flowering stage			ripening stage		
		CK	U	SRU	CK	U	SRU	CK	U	SRU
Ba1										
Mesorhabditis	*Mesorh*	0.0	0.0	0.4	0.6	0.4	0.0	1.8	1.0	0.4
Monhyster	*Monhy*	1.0	0.0	1.3	0.0	0.0	0.8	0.9	0.4	0.6
Panagrolaimus	*Panag*	0.9	2.7	1.1	5.9	2.1	6.2	1.4	1.0	3.5
Pelodera	*Pelodera*	0.0	0.6	0.5	0.8	1.4	0.9	2.3	2.6	1.9
Protorhabditis	*Protor*	5.3	6.1	8.9	3.8	4.8	5.0	5.4	4.2	4.0
Ba2										
Acrobeles	*Acro*	0.6	0.7	0.8	2.1	1.0	0.6	0.6	0.7	0.8
Acrobeloides	*Acrob*	24.5	20.0	19.7	13.8	13.4	13.3	11.5	10.6	11.3
Cephalobus	*Cepha*	5.5	4.6	1.5	1.0	0.6	0.6	1.4	0.4	0.4
Cervidellus	*Cervi*	1.0	0.9	0.0	0.8	0.0	0.0	0.8	0.6	1.3
Chiloplacus	*Chilo*	0.0	1.3	1.4	1.3	2.0	0.8	2.4	2.3	4.0
Eucephalobus	*Eucep*	0.0	0.0	0.0	0.3	1.1	0.6	0.7	0.8	0.6
Heterocephalobus	*Hetero*	6.0	3.9	6.2	6.7	6.0	5.4	5.5	6.8	6.4
Plectus	*Plect*	1.8	4.2	2.3	3.5	1.7	3.4	1.8	0.0	2.0
Wilsonema	*Wilso*	0.0	0.0	0.0	0.0	0.7	0.0	0.4	0.6	0.6
Ba3										
Prismatolaimus	*Prism*	0.0	2.0	1.1	1.3	2.4	0.8	0.8	2.2	1.0
Rhabdolaimus	*Rhabd*	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Ba4										
Alaimus	*Alaim*	0.0	1.6	0.0	0.0	0.0	0.8	0.0	0.6	0.6
Fu2										
Aphelenchoides	*Aphels*	5.7	7.7	10.0	7.2	5.6	4.9	5.5	6.2	5.8
Aphelenchus	*Aphedes*	10.6	9.0	10.2	11.6	11.5	10.2	8.0	10.0	10.1
Bursaphelenchus	*Bursa*	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.0	0.0
Ditylenchus	*Dityl*	1.1	0.6	2.6	4.8	6.2	3.5	6.0	6.5	5.9
Fu3										
Diphtherophora	*Dipht*	0.0	0.0	0.7	0.4	1.2	1.0	0.8	0.6	0.6
Fu4										
Dorylaimoides	*Doryl*	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Tylencholaimus	*Tylen*	3.8	3.5	1.5	1.1	1.0	2.6	1.7	1.8	0.8
Om4										
Dorydorella	*Doryd*	0.6	0.6	2.8	2.7	3.9	5.7	3.5	2.1	2.1
Microdorylaimus	*Micro*	5.5	4.7	7.5	7.3	8.3	5.1	5.7	5.7	5.0
Kochinema	*Kochi*	0.0	0.0	0.0	0.0	1.0	0.6	0.6	0.6	0.0
Thonus	*Thonu*	0.7	0.0	0.5	0.7	1.0	0.6	4.1	2.7	4.8
Ca5										
Aporcelaimellus	*Aporc*	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0
Discolaimus	*Disco*	0.6	0.0	0.5	0.5	0.4	0.4	0.0	0.4	1.2
Mesodorylaimus	*Mesod*	0.9	0.0	0.5	1.0	1.8	0.2	0.0	0.9	0.0
H2										
Filenchus	*Filen*	1.2	4.2	1.3	3.0	5.3	7.1	7.2	6.5	4.8
Malenchus	*Malen*	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Paratylenchus	*Parat*	1.8	0.9	0.6	0.7	0.4	0.8	0.0	0.4	0.8
Psilenchus	*Psile*	0.0	0.9	0.0	0.0	0.0	0.8	0.4	0.0	0.0
Tylenchus	*Tylen*	1.4	2.2	0.5	1.2	0.8	0.6	0.0	4.6	2.2

(*Continued*)

guild*/genus	genus abbreviation	seedling stage			flowering stage			ripening stage		
		CK	U	SRU	CK	U	SRU	CK	U	SRU
H3										
Helicotylenchus	*Helic*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.4
Heterodera	*Hetero*	18.6	16.2	15.0	12.7	12.8	12.8	10.3	10.1	9.5
Scutylenchus	*Scuty*	0.9	0.9	0.0	2.5	1.0	2.9	1.6	1.9	2.7
Tylenchorhynchus	*Tylenc*	0.0	0.0	0.7	0.0	0.0	0.0	4.2	3.2	3.9
H5										
Longidorus	*Longi*	0.0	0.0	0.0	0.0	0.0	0.6	0.4	0.0	0.0

*Guild designation is the composite of feeding habit and cp value: Ba, bacterivore; Fu, fungivore; Om, omnivore; Ca, carnivore (predator); H, herbivore. Numbers following the letters indicate the cp value of each taxon (Bongers, 1990; Bongers and Bongers, 1998; Ferris and Matute, 2003).

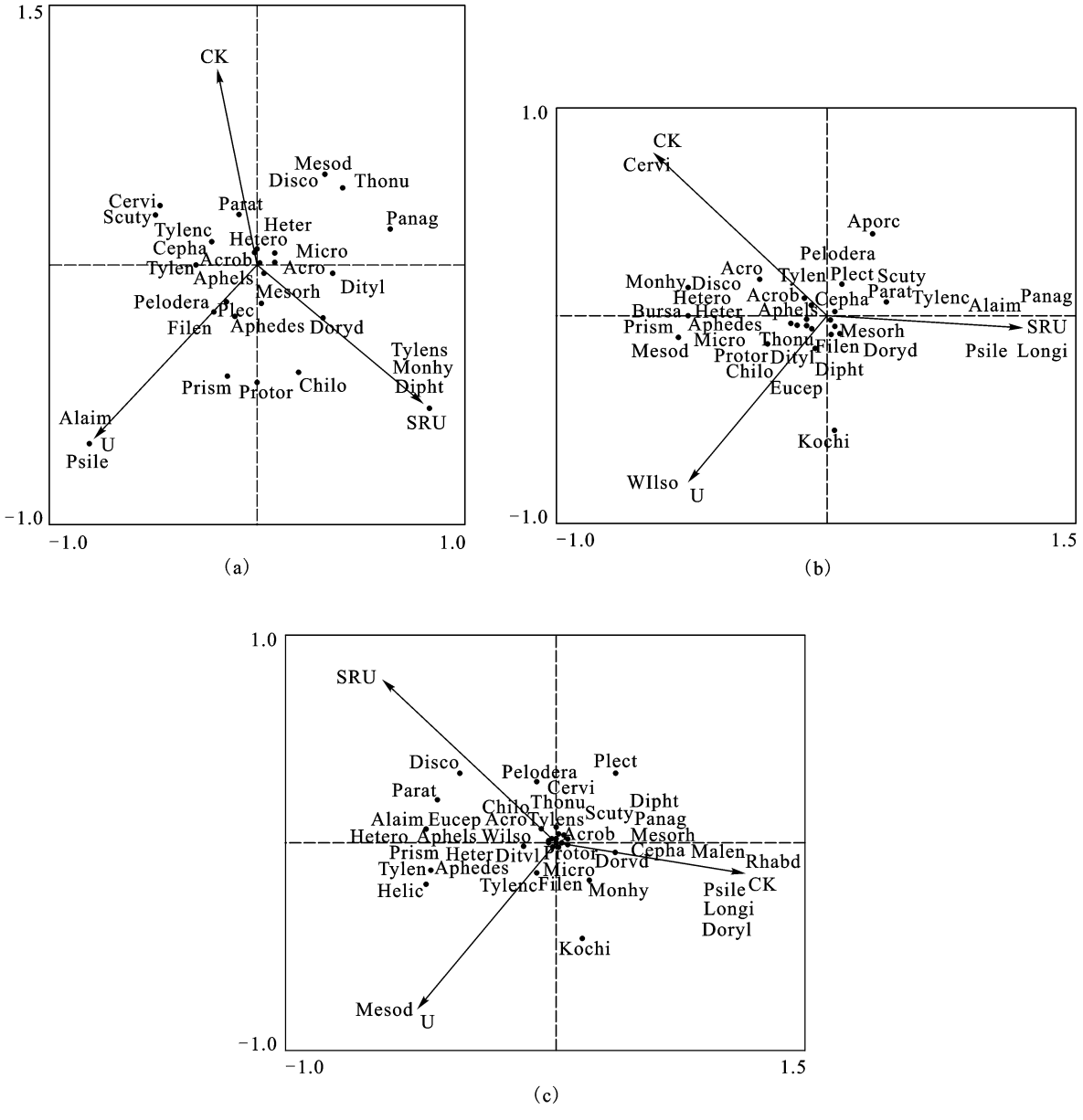

Fig. 3 Canonical correspondence analysis bio-plot of soil nematode genera and environmental variables (fertilizer treatments were treated as environmental variables)

Table 3 Statistical values for the first axis of CCA performed on soil nematode genera during soybean growing season

item	seedling	flowering	ripening
eigenvalue	0.101	0.080	0.091
genera-environment correlations	0.913	0.911	0.951
cumulative percentage variance of generic data	19.4	19.4	23.5
test of significance (*P*-value)	0.042	0.008	0.002

CCA:Canonical correspondence analysis.

Table 4 Abundance of nematode guilds and dominant genera under different treatments during soybean growing season

unit: individuals per 100 g dry soil

	seedling stage			flowering stage			ripening stage		
	CK	U	SRU	CK	U	SRU	CK	U	SRU
abundance of nematode guilds									
Ba1	7 ± 3	11 ± 5	21 ± 9	29 ± 12	18 ± 6	31 ± 3	34 ± 4	23 ± 8	36 ± 9
Ba2	32 ± 2	33 ± 6	50 ± 6	68 ± 9	54 ± 2	60 ± 2	73 ± 9	56 ± 6	92 ± 5
Ba3	–	–	–	–	–	–	6 ± 2	–	–
Ba4	–	1 ± 1	–	–	–	2 ± 1	–	2 ± 1	2 ± 1
Fu2	18 ± 7	17 ± 4	37 ± 8	53 ± 3	48 ± 4	47 ± 6	57 ± 5	57 ± 7	74 ± 5
Fu3	–	–	1 ± 1	1 ± 0	3 ± 2	3 ± 2	2 ± 1	2 ± 1	2 ± 1
Fu4	4 ± 1	4 ± 1	2 ± 1	3 ± 1	2 ± 1	6 ± 1	7 ± 4	5 ± 1	3 ± 1
Om4	6 ± 2	6 ± 2	17 ± 2	27 ± 9	30 ± 6	29 ± 1	41 ± 9	28 ± 4	41 ± 4
Ca5	1 ± 1	–	2 ± 1	5 ± 2	4 ± 3	2 ± 1	–	4 ± 1	4 ± 2
H2	4 ± 1	8 ± 2	4 ± 2	12 ± 3	14 ± 4	26 ± 10	24 ± 2	28 ± 8	27 ± 4
H3	17 ± 3	16 ± 2	25 ± 4	37 ± 7	29 ± 5	40 ± 7	47 ± 7	40 ± 4	57 ± 6
H5	–	–	–	–	–	2 ± 1	1 ± 1	–	–
dominant genera									
Acrobeloides	20 ± 1	18 ± 2	31 ± 3	32 ± 3	27 ± 1	33 ± 4	33 ± 2	26 ± 1	39 ± 3
Aphelenchus	10 ± 4	9 ± 3	16 ± 3	27 ± 3	23 ± 4	25 ± 2	23 ± 2	25 ± 1	35 ± 5
Herterodera	16 ± 3	15 ± 2	24 ± 4	30 ± 5	26 ± 4	33 ± 6	30 ± 2	25 ± 1	33 ± 7

Data are $x \pm SE$.

4 Discussion

In our investigation, the concentrations of NH_4^+–N were lower in SRU than in U, and those of NO_3^-–N were higher in SRU than in CK and U during soybean growing season. These conclusions are consistent with those of Liang et al. (2005), who observed similar results during the wheat growing season. With the application of slow-release urea, the urease activity was inhibited by urease inhibitor and the hydrolyzation of urea was restrained. Slower hydrolyzation process of urea prolonged the diffusion time of urea, decreased the concentration of NH_4^+–N and reduced the harm to seedlings (Hua et al., 2008). This result indicates that the incorporation of urease inhibitor can maintain N as NH_4^+ for a longer time, so that more fertilizer derived-N could be taken up by the plants and fixed by the organic component of soil (Gioacchini et al., 2002). However, the concentration of NO_3^-–N was high in SRU. Hua et al. (2008) thought that the synergistic effect of urease and nitrification inhibitor was better than the individual effect of urease inhibitor. Therefore, we suggest that combined application of urease and nitrification inhibitors be conducted in the field in order to further improve the efficiency of slow-release urea N.

Soil nematode communities can provide unique insight into many aspects of soil processes (Neher, 2001). In the present study, the numbers of total nematodes were increased significantly stimulated by SRU compared to other treatments. This shows that the application of slow-release fertilizer could positively affect the soil nematode communities. The low abundance of soil nematodes in U might be caused by the excessive N that occurred, which had adverse effects on soil organisms when the release process of urea cannot be controlled (Ferris et al., 2004).

In addition, bacterivores with cp 2–3, fungivores with cp 2 and herbivores with cp 3 among the treatments were

significant. Bacterivores and fungivores with cp 2 and herbivores with cp 3 were higher in SRU than in CK and U. Bacterivores with cp 2 did not exist in the treatment with urea. The lower concentration of soil mineral N in slow-release urea was not sufficient to change the numbers of trophic groups such as bacterivores and fungivores (Liang et al., 2005). However, our study proved that the effect of slow-release urea can be indicated by the nematode guilds which combined trophic groups with cp values. The numbers of *Acrobeloides* belonging to bacterivores and *Aphelenchus* belonging to fungivores were higher in SRU. Bacterivores and fungivores could act via the soil microbial component in stimulating decomposition and nitrogen mineralization (Ferris et al., 1998, 2004). Hua et al. (2006) believed that bacterivores could enhance nutrient cycling through feeding on microbes, excreting labile nutrients and transporting microbial propagules.

Through the analysis of canonical correspondence on soil nematode genera and treatment, we found that there were various responses among different genera at different growth stages and that the soil nematode community composition was related to the fertilizer treatment. More organism groups had greater abundance in SRU than in CK and U. Thus, we can conclude that positive inter-feedback was formed between soil nematodes and slow-release urea which promoted the virtuous nutrient cycling.

In conclusion, slow-release urea fertilization has a positive effect on soil nematode community structure compared with conventional urea fertilizer in the soybean field. Soil nematode guilds and genera are good indicators of the biological effect of the slow-release urea fertilizer. The positive inter-feedback between soil nematodes and slow-release urea benefits nutrient cycling.

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References

Bardgett R D, Cook R, Yeates G W, Denton C S (1999). The influence of nematodes on below-ground processes in grassland ecosystems. Plant Soil, 212: 23–33

Bongers T (1990). The maturity index: an ecological measure of environmental disturbance based on nematode species composition. Oecologia, 83: 14–19

Bongers T, Bongers M (1998). Functional diversity of nematodes. Appl Soil Ecol, 10: 239–251

Ekschmitt K, Bakonyi G, Bongers M, Bongers T, Bosr m S, Dogan H, Harrison A, Nagy P, O'Donnell A G, Papatheodorou E M, Sohlenius B, Stamou G P, Wolters V (2001). Nematode community structure as indicator of soil functioning in European grassland soils. Eur J Soil Biol, 37: 263–268

Ferris H, Venette R C, van der Meulen H R, Lau S S (1998). Nitrogen mineralization by bacterial-feeding nematodes: Vertification and measurement. Plant Soil, 203: 159–171

Ferris H, Matute M M (2003). Structural and functional succession in the nematode fauna of a soil food web. Appl Soil Ecol, 23: 93–110

Ferris H, Venette R C, Scow K M (2004). Soil management to enhance bacterivore and fungivore nematode populations and their nitrogen mineralization function. Appl Soil Ecol, 25: 19–35

Gioacchini P, Nastri A, Marzadori C, Giovannini C, Antisare L V, Gessa C (2002). Influence of urease and nitrification inhibitors on N losses from soils fertilized with urea. Biol Fertil Soils, 36: 129–135

Gruzdeva L I, Matveeva E M, Kovalenko T E (2007). Changes in soil nematode communities under the impact of fertilizers. Eurasian Soil Sci, 40: 681–693

Hua J F, Jiang Y, Liang W J (2006). Response of nematodes in a Hapli-Udic Argosol to urea amended with urease and nitrification inhibitors. Pedosphere, 16: 428–434

Hua J F, Jiang Q, Shi C J, Zhuang Q L, Jiang Y (2008). Effects of urease/nitrification inhibitors on soil urease activity, soil available N and the yield of spring wheat. Chin J Soil Sci, 39: 94–99 (in Chinese)

Ingham R E, Trofymow J A, Ingham E R, Coleman D C (1985). Interactions of bacteria, fungi and their nematode grazers: effects on nutrient cycling and plant growth. Ecol Monogr, 55: 119–140

Li Q, Liang W J, Jiang Y, Shi Y, Zhu J G, Neher D A (2007). Effect of elevated CO_2 and N fertilization on soil nematode abundance and diversity in a wheat field. Appl Soil Ecol, 36: 63–69

Li Q, Liang W J, Ou W (2008). Responses of nematode communities to different land uses in an aquic brown soil. Front Biol China, doi: 10.1007/s11515-008-0063-5

Liang W J, Li F P, Li Q, Zhang W D (2007a). Temporal dynamics of soil nematode community structure under invasive *Ambrosia trifida* and native *Chenopodium serotinum*. Helminthologia, 44: 29–33

Liang W J, Li Q, Jiang Y, Neher D A (2005). Nematode faunal analysis in an aquic brown soil fertilized with slow-release urea, Northeast China. Appl Soil Ecol, 29: 185–192

Liang W J, Lou Y L, Li Q, Zhong S, Zhang X K, Wang J K (2008). Nematode faunal response to long-term application of nitrogen fertilizer and organic manure in Northeast China. Soil Biol Biochem, doi: 10.1016/j.soilbio.2008.06.018

Liang W J, Zhong S, Hua J F, Cao C Y, Jiang Y (2007b). Nematode faunal response to grassland degradation in Horqin Sand Land. Pedosphere, 17: 611–618

Mulvaney R L (1996). Nitrogen-Inorganic. In: Sparks D L, ed. Methods of Soil Analysis. Part 3. Madison: Soil Science Society of America Book Series 5, 1123–1124

Neher D A (2001). Role of nematodes in soil health and their use as indicators. J Nematol, 33: 161–168

Okada H, Harada H (2007). Effects of tillage and fertilizer on nematode communities in a Japanese soybean field. Appl Soil Ecol, 35: 528–598

Tsiafouli M A, Argyropoulou M D, Stamou G P, Sgardelis S P (2007). Is duration of organic management reflected on nematode communities of cultivated soils? Belg J Zool, 137: 165–175

Wang K H, McSorley R, Marshall A, Gallaher R N (2006). Influence of organic *Crotalaria juncea* hay and ammonium nitrate fertilizers on soil nematode communities. Appl Soil Ecol, 31: 186–198

Yeates G W, Bongers T (1999). Nematode diversity in agroecosystems. Agric Ecosyst Environ, 74: 113–135

Yeates G W, Bongers T, de Goede R G M, Freckman D W, Georgieva S S (1993). Feeding habits in soil nematode families and genera —an outline for soil ecologists. J Nematol, 25: 315–331

Zhou L K, Chen L J, Li R H, Wu Z J (2003). Behavior of soil urea N and its regulation through incorporating with inhibitors hydroquinone and dicyandiamide. In: Ji L Z, Chen G X, Schnug E, Hera C, Hanklaus S, eds. Fertilization in the Third Millenium — Fertilizer, Food Security and Environmental Protection (Proceedings vol. II). Shenyang: Liaoning Science and Technology Publishing House, 1175–1192