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Effects of Wetland Utilization Change on Spatial Distribution of Soil Nematodes in Heihe River Basin, Northwest China

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Abstract: The first account of the effects of wetland reclamation on soil nematode assemblages were provided, three sites in Heihe River Basin of Northwest China, that is grass wetland (GW), *Tamarix chinensis* wetland (TW) and crop wetland (CW) treatments, were compared. Results showed that the majority of soil nematodes were presented in the 0–20 cm soil layers in CW treatments, followed by in the 20–40 cm and 40–60 cm layers in GW treatments. Plant-feeding nametodes were the most abundant trophic groups in each treatment, where GW (91.0%) > TW (88.1%) > CW (53.5%). Generic richness (GR) was lower in the TW (16) than that in GW (23) and CW (25). The combination of enrichment index (EI) and structure index (SI) showed that the soil food web in GW was more structured, and those in TW was stressed, while the enrichment soil food web was presented in the CW treatment. Several ecological indices which reflected soil community structure, diversity, Shannon-Weaver diversity (H′), Evenness (J′), Richness (GR) and modified maturity index (MMI) were found to be effective for assessing the response of soil namatode communities to soil of saline wetland reclamation. Furthermore, saline wetland reclamation also exerted great influence on the soil physical and chemical properties (pH, Electric conductivity (EC), Total organic carbon (TOC), Total nitrogen (Total-N) and Nitrate Nitrogen (N-NO_3^-)). These results indicated that the wetland reclamation had significantly effects on soil nematode community structure and soil properties in this study.

Keywords: soil nematode; spatial distribution; community structure; ecological index; wetland exploration

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1 Introduction

As the boundaries between terrestrial and aquatic ecosystems, wetlands are the most important parts of terrestrial ecosystems and perform valuable ecosystem services such as flood protection, water quality enhancement, conservation of biological diversity and carbon sequestration (Verhoeven and Setter, 2010). However, different types of human disturbance such as wetland reclamation have a significant effect on the detritus food web and soil fauna communities, especially for nematodes (Nico *et al*., 2013). Soil nematodes regulate the turnover of microbial communities, contribute to several trophic components of food webs and may play essential roles in ecosystem functioning. They 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 to microflora (Zhang *et al*., 2015).

Nematodes are ubiquitous inhabitants and usually

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numerically dominant in marine, freshwater and terrestrial habitats (Wu *et al*., 2005; Ugarte *et al*., 2013). They occupy a central position in the detritus food web by regulating rates of soil organic matter decomposition, mineralization of plant nutrients, and nutrient cycling (Zhi *et al*., 2008). Since soil nematodes form one of dominant belowground communities in soil ecosystems (Li *et al*., 2009), the study of their responses can help us better understand the belowground ecosystems processes response to various kinds of soil perturbations, such as, addition of mineral nitrogen fertilizers, cultivation and different land uses, affect species richness, trophic structure, and the succession status of nematode communities (Hodson *et al*., 2014). Several characteristics of soil nematodes such as abundant in virtually all environments, diversity of life strategies and feeding habits, short life cycles, and relatively well-defined sampling procedures etc, make them to be a good candidates for bioindicators of the status and processes of soil ecosystems (Yeates, 2003; Liang *et al*., 2007). Some researchers have demonstrated that the abundance, diversity and species composition of soil nematode communities could reflect the variation of the disturbed environment. In recent years, according to the concepts of functional guilds, new nematode faunal indices including enrichment index (EI), basal index (BI), structural index (SI) and channel index (CI) have been developed and applied in soil food web diagnostics and succession (Ferris *et al*., 2001; Liang *et al*., 2005; Zhang *et al*., 2007). On forest, grassland and farmland, a considerable studies on the bioindicator of nematode faunal were conducted (Bloemers *et al*., 1997; Porazinska *et al*., 1999; Yeates, 2003). However, the characteristics of nematode assemblages in saline wetland soils are poorly known (Neher *et al*., 2001; Wu *et al*., 2002), and little information in the field on wetlands reclamation affects on soil nematode faunal in wetlands of arid and semi-arid region of China.

The Heihe River is the second largest inland river in the arid and semi-arid region in Northwest China. Zhangye City located in this region and about 21 0456 ha of wetland distributed in this city. Wetlands of this region play an important role in regulating air humidity and maintaining biodiversity, especially the contribution of the wetlands to stabilizing the shifting sand dunes, reducing the damage of sandstorm, prohibiting the Southern threaten of Badain Jaran Desert, and the sustainable developments of the Heihe region. However, since 1980s local government allocated parts of the wetlands to farmers, which resulted in mass of wetlands have been reclaimed for *Tamarix chinensis* plantation or drained to convert them into agricultural land. The reclamation of local people caused the salt marshes of the Heihe River basin wetland are subjected to both physical variability and nutrient variability, also affect the process of belowground ecosystem. Several previous studies have shown that anthropogenic stressors can disrupt the emergence process, resulting in depauperate communities and biodiversity loss (Gordon, 1994; Yeates *et al*., 1999; Kennish, 2002). For example, the soil nematodes inhabiting in these wetlands must be able to respond to the reclamation of wetlands, because the inhabitants of nematode faunal is increasingly threatened due to the habitat destruction.

Therefore, we speculated that the changes of the belowground process and the microorganisms' biodiversity may impact the soil nematode faunal, and the purpose of this study was to determine the relationships between wetland reclamation and soil nematodes, and it is essential for understanding soil ecosystem process and adaptive wetland ecosystem management in this area.

2 Materials and Methods

2.1 Study site and experimental design

This study was conducted at the Liaoquan town (39°12′–39°20′N, 100°09′–100°15′E), in Zhangye City, Gansu Province. Large area of salt marsh distributed in this region. This region has a typical desert climate and is characterized by cold winter and dry hot summer, with mean annual temperature of 7.6℃–7.9℃, mean annual precipitation of 116.8 mm, and mean annual evaporation of 2390 mm.

Three treatments were imposed on these wetlands according to the types of exploitation: a, a relatively unaffected grass wetland (GW) as control; b, the wetland have been planted with *Tamarix chinensis* (TW) for about 10 years over; and c, the wetland cultivated for agricultural crop after drawing the excessive water (CW). Three 10 m × 10 m plots, which were about 500 m apart from each other and had similar coverage, were chosen in each type of wetland as replicates. In GW treatments, the varieties of grass were relatively abundant and the total vegetation coverage is 45% approximately. In TW treatments, *Tamarix chinensis*, which is a typical salt-tolerant genotype shrubs species in salt marshes of China, contributing about 35% of total coverage. The cropland have been cultivating for Sugarbeet (*Beta vulgaris*), which is an economical crop and suit to the salt marshes soil, about 10 years. Fertilizers were applied at a rate of 225 kg N/ha, 60 kg P/ha and 112 kg K/ha.

2.2 Sampling, extraction and identification of nematodes

Sampling was carried out on 24–25th September 2013 from the Heihe River wetland, in Zhangye City of Gansu Province, China. The samples were collected using a soil corer of 2.5 cm in diameter with three replications in each type of wetland at the depths of 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm. Each sample, comprised of six soil cores, was placed in individual plastic bag and transported to the laboratory for chemical and nematode analyses.

Nematodes were extracted from 100 g soil sample (fresh weight) by a modified cotton-wool filter method (Oostenbrink, 1960; Townshend, 1963). The nematode populations were expressed as number of nematodes per 100 g dry weight soil. After counting the number of total nematodes (TNE), 100 specimens per sample were randomly selected and indentified to genus level using an inverted compound microscope.

2.3 Soil chemical analysis

Soil pH was determined with a glass electrode in 1 : 2.5 soil : water solution (w/v). Soil salinity was determined in soil extracts and expressed as electrical conductivity (EC). Soil organic carbon (SOC) was analyzed by dry combustion, using Total C analyzer (Shimadzu TOC 5000, Japan). Total nitrogen was determined by the method of Kjeldahl digestion (Sun *et al*., 2005), and soil N-NO_3^- was determined by extraction with 2 M KCl, steam distillation and titration (Mulvaney, 1996). Soil chemical properties under different treatments were shown in Table 1.

2.4 Nematode community analyses

Nematode ecological indices were calculated by the following approaches:

(1) Shannon-Weaver diversity index (H')

$$H' = -\sum p_i(\ln p_i) \tag{1}$$

where p_i is the proportion of individuals in the ith taxon.

Table 1 Changes in soil chemical parameters among different treatments at different sampling depths

Parameter	Treatment	Sampling depth (cm)					Effect		
		0–20	20–40	40–60	60–80	80–100	Treatment	Depth	Treatment × Depth
pH	GW	8.49±0.12A	8.36±0.13A	8.18±0.11A	8.26±0.07A	8.37±0.10A	**	*	NS
	TW	8.61±0.04A	8.36±0.14A	8.28±0.16A	8.48±0.15A	8.44±0.03A			
	CW	8.68±0.03A	8.61±0.04A	8.48±0.03A	8.51±0.08A	8.62±0.09A			
EC (ms/cm)	GW	5.14±2.16B	2.82±1.25B	3.52±0.45A	1.28±0.29A	4.59±3.69A	**	*	*
	TW	11.05±1.52A	4.81±2.62A	3.27±1.77A	1.41±0.08A	0.77±0.11B			
	CW	0.31±0.01C	0.35±0.01C	0.67±0.25B	0.66±0.18B	0.66±0.26B			
TOC (mg/kg)	GW	11.26±0.79A	8.73±0.37ABb	7.55±0.63A	5.72±0.48A	4.83±0.52A	**	**	NS
	TW	8.74±0.47B	6.49±0.30B	7.01±0.57A	4.24±0.42A	3.72±0.46A			
	CW	12.67±0.68A	10.49±1.55A	7.29±1.55A	5.56±1.50A	3.85±0.98A			
Total-N (mg/kg)	GW	0.53±0.06B	0.44±0.02B	0.41±0.01A	0.35±0.02A	0.31±0.04A	**	**	**
	TW	0.47±0.02B	0.36±0.01B	0.39±0.01A	0.25±0.01B	0.25±0.04A			
	CW	0.76±0.04A	0.56±0.05A	0.46±0.01A	0.34±0.02A	0.24±0.05A			
N-NO_3^- (mg/kg)	GW	0.89±0.13A	0.27±0.02B	0.17±0.01B	0.16±0.01B	0.16±0.01B	**	**	NS
	TW	0.94±0.23A	0.31±0.03B	0.23±0.03AB	0.21±0.01AB	0.19±0.01B			
	CW	1.14±0.30A	0.75±0.11A	0.58±0.13A	0.48±0.11A	0.43±0.12A			

Notes: Mean values and standard deviation of three replicates are presented. Different uppercase letters in same column indicate significant differences of variable means among different treatments for each soil depth ($P < 0.05$). GW, grass wetland; TW, tamarix chinensis wetland; CW, crop wetland. EC, electric conductivity; TOC, total organic carbon; Total-N, total nitrogen; N-NO_3^-, nitrate nitrogen. **, $P < 0.01$; *, $P < 0.05$; NS: non-significant ($P > 0.05$)

(2) Pielou′s evenness index (J')

$$J' = H' / H'_{\max} \quad (2)$$

(3) Generic richness

$$GR = (S - 1)/\ln(N) \quad (3)$$

where S is the number of taxa and N is the number of TNE (Yeates and Bongers, 1999).

(4) Modified maturity index (MMI)

$$MMI = \sum v(i)\cdot \mathrm{f}(i) \quad (4)$$

where $v(i)$ is the *cp* value of taxon i according to their r and K characteristics following Bongers (1990), and $\mathrm{f}(i)$ is the frequency of taxon i in a sample (Yeates *et al.*, 1993).

(5) Structural index (SI)

$$SI = 100 \times (s / (b + s)) \quad (5)$$

(6) Enrichment index (EI)

$$EI = 100 \times (e / (e + b)) \quad (6)$$

(7) Basal index (BI)

$$BI = 100 \times (b / (b + e + s)) \quad (7)$$

where in equations (5), (6) and (7), b is the abundance of individuals in the basal component weighted by their k_b values, e is the abundance of individuals in guilds in the enrichment component weighted by their respective k_e values, and s is the abundance of individuals in the structural component weighted by their k_s values, k_e is the weighting assigned to guilds Ba_1 and Fu_2, k_b is the weighting assigned to guilds Ba_2 and Fu_2, and k_s is the weighting assigned to guilds Ba_3–Ba_5, Fu_3–Fu_5, Om_4–Om_5, Ca_2–Ca_5 (Ferris *et al.*, 2001). Ba_x, Fu_x, Ca_x, Om_x, H_x represent the functional guilds of nematodes that are bacterivores (Ba), fungivores (Fu), carnivores (Ca), omnivores (Om) or herbivores (H) (Yeates *et al.*, 1993) where the guilds have the character indicated by x on the colonizer–persister (*cp*) scale (1–5) according to their r and K characteristics following Bongers (1990) and Bongers and Bongers (1998); and nematodes in the same functional guilds respond similarly to food web enrichment and environmental perturbation.

2.5 Statistical analysis

Nematode abundances were $\ln(x + 1)$ transformed prior to statistical analysis and expressed as numbers per 100 g dry soil. Soil physical and chemical properties were analyzed through a two-way ANOVA (treatment × sampling depth) to determine the between-subject effects; LSD was then performed as a post hoc test to assess the treatment effects on each sampling depth. As most of the nematode data in this investigation presented heteroscedasticity, multiple comparisons of nematode abundances and ecological indices were performed with the non-parametric Kruskal-Wallis test, subsequently, Mann-Whitney test was used to assess treatment effects on each sampling depth. Spearman′s correlation test was used to assess the correlation between nematodes and selected soil physical and chemical properties. All statistical analyses were performed by SPSS software package and differences with $P < 0.05$ and $P < 0.01$ were considered significant and highly significant respectively.

3 Results

3.1 Number of TNE

At the different depths of wetland soil, the number of TNE fluctuated obviously among different types of wetland (Fig. 1), with the highest value (584 individuals/100 g soil) in CW at the 0–20 cm, and lowest (19 individuals/100 g soil) in TW at the 80–100 cm. Significant differences among the types of wetland and sampling depth were observed in the numbers of TNE ($P < 0.01$). At the depth of 0–20 cm the numbers of TNE were significantly higher in CW than those in GW and TW, while at the other depths of soil the numbers of TNE were significantly higher in GW than those in TW and CW (Fig. 1).

3.2 Nematode composition

Thirty genera of soil nematodes were identified during the course of the study (Table 2). The highest number of genera (25) was found in CW, whereas, the lowest number of genera (16) was found in TW. Significant effects were found in the numbers of genera ($P < 0.05$). Among the six genera belonging to the herbivores of cp-3 guild, *Helicotylenchus* and *Pratylenchus* were the predominant genera in all treatments; *Heterodera* and *Macroposthonia* were only dominant in TW and GW, respectively (> 5%). Of the seven genera in the herbivores of cp-2 guild, *Paratylenchus* was observed the most abundant genus in GW, while *Coslenchus* and *Neopsilenchus* with higher relative abundance observed in CW and GW in comparison with TW. Among the ten

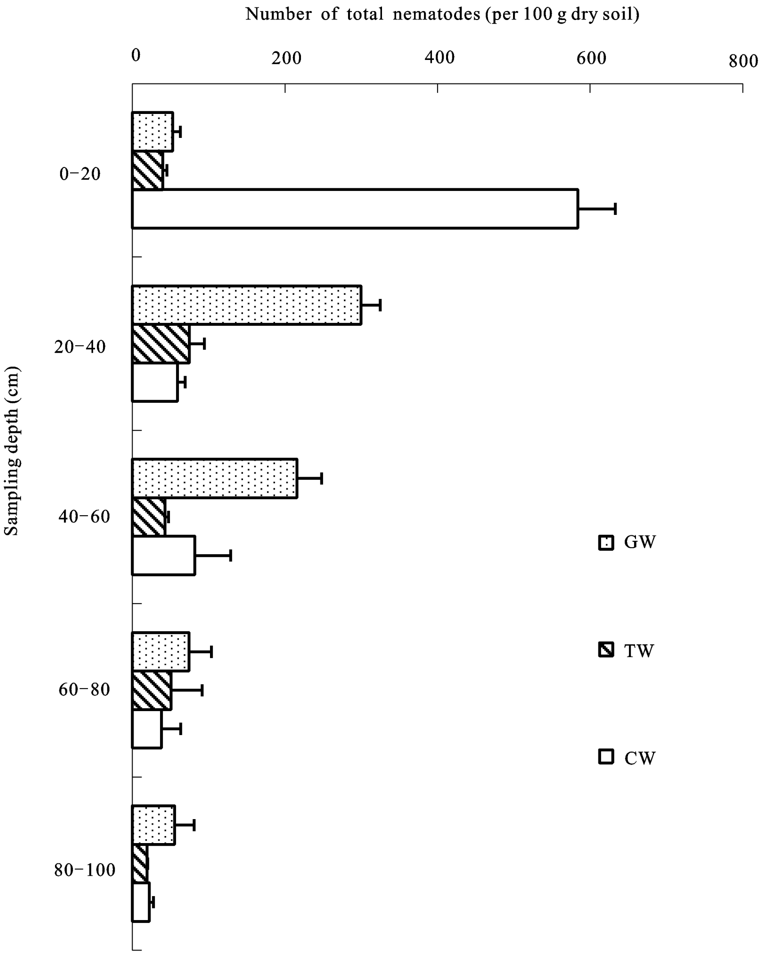

Fig. 1 Changes in numbers (individuals per 100 g dry soil) of number of total nematodes (TNE) among different treatments at different sampling depth. Error-bars represent the standard error

genera belong to the bacterivores, *Protorhabditis* was dominant in the bacterivores of cp-1 guild in CW, *Acrobeloides* in the bacterivores of cp-2 guild was most prevalent in CW, followed by TW and GW. While of the four genera belonging to the fungivores, most of the genera were found in GW and CW, there were only two genera *Aphelenchoides* and *Tylencholaimus* in TW. Omnivores was appeared in each of the treatments but not dominant (< 5%). Statistical analysis was conducted on the dominant genera (relative abundance higher than 5% in all treatments).

3.3 Nematode functional guilds

During the study period, significant treatment and/or sampling depth effects were observed in the numbers of different functional guilds (Table 3), except omnivores of cp-4 guilds. At the 0–20 cm depth, the numbers of bacterivores of cp-1, 2, 3 guilds, fungivores of cp-2, 4 guilds, herbivores of cp-2, 3 guilds and omnivores of cp-5 guild were higher in CW than those in GW and TW. Except the 0–20 cm depth, the numbers of herbivores of cp-2, 3 guilds were higher in GW than those in TW and CW across the sampling depth. Except the bacterivores of cp-3 guild, omnivores of cp-5 guild and herbivores of cp-2 guild, significant sampling depth effects were found on the bacterivores, fungivores, omnivores and herbivores guilds at each treatment (Table 3).

3.4 Nematode ecological indices

The nematode ecological indices and the values of SI, EI and BI fluctuated across all sampling depths in the different types of wetland (Table 4). At each sampling depth, significant effects were observed on the ecological indices and the values of SI, EI and BI ($P < 0.05$), while sampling depth have only significant effects on H′, SI and BI (Table 4). In all the depth of soil,

Table 2 Proportional contribution (%) of various nematodes to nematode assemblage under different treatments

Genus	Guild^a	GW	TW	CW
Ablechroiulus	Ba$_1^b$	0.0	0.0	0.1
Protorhabditis	Ba$_1$	0.0	0.6	7.7
Diploscapter	Ba$_1$	0.0	0.0	0.1
Turbatrix	Ba$_1$	0.1	0.0	1.1
Eucephalobus	Ba$_2$	0.0	0.9	2.4
Acrobeloides	Ba$_2$	2.0	7.5	19.4
Eumonhystera	Ba$_2$	0.1	0.3	0.7
Wilsonema	Ba$_2$	0.1	0.0	0.0
Paracyatholaimus	Ba$_3$	0.0	0.0	0.4
Prismatolaimus	Ba$_3$	0.1	0.0	0.8
Paraphelenchus	Fu$_2$	0.3	0.0	3.5
Aphelenchoides	Fu$_2$	0.4	0.6	1.7
Dorylaimoides	Fu$_4$	0.6	0.0	4.9
Tylencholaimus	Fu$_4$	2.4	0.6	0.8
Clarkus	Om$_4$	0.1	0.0	0.1
Trichodorus	Om$_4$	0.0	0.0	0.1
Aporcelaimium	Om$_5$	2.7	1.5	2.2
Coslenchus	H$_2$	7.0	2.4	8.8
Neopsilenchus	H$_2$	6.0	4.2	7.3
Tylenchus	H$_2$	0.1	0.0	0.0
Filenchus	H$_2$	0.4	1.8	0.0
Psilenchus	H$_2$	0.0	0.0	0.8
Ecphyadophora	H$_2$	0.1	0.0	0.0
Paratylenchus	H$_2$	18.5	1.5	3.5
Scutylenchus	H$_3$	1.1	3.9	1.1
Helicotylenchus	H$_3$	35.2	37.6	16.9
Pratylenchus	H$_3$	9.1	14.9	14.7
Heterodera	H$_3$	0.1	17.6	0.1
Macroposthonia	H$_3$	13.3	4.2	0.3
Criconema	H$_3$	0.1	0.0	0.0
No. of genera		23	16	25

Notes: a, functional guilds of soil nematodes characterized by feeding habits and life-history characters; b, numbers following the functional groups represent the *cp* values (Bongers and Bongers, 1998; Ferris *et al*., 2001). Ba, bacterivores; Fu, fungivores; Om, Omnivores; H, plant-parasites; GW, grass wetland; TW, tamarix chinensis wetland; CW, crop wetland

the values of H′ and GR were higher in CW than those in GW and TW, higher values of J′ were observed in CW and TW than those in GW. An opposite trend was observed in the values of MMI which was lower in CW and TW compared with GW at the 0–20 cm and 20–40 cm depths, while higher values of MMI in TW than that in CW and GW at the 40–60 cm, 60–80 cm and 80–100 cm depths. Except at the 0–20 cm depth, the values of SI were higher in GW than those in TW and CW, while the values of EI were higher in CW than those in GW and TW at the four previous depths.

3.5 Correlations of nematode functional guilds and ecological indices with soil chemical properties

During the study period, pH values were only negatively correlated with the values of SI (Table 5). The values of EC were positively correlated with the values of BI and negatively with EI. The numbers of bacterivores of cp-1, 2, 3 guilds, fungivores of cp-2, 4 and omnivores of cp-5 guilds, and the values of BI, were negatively with the values of EI. The contents of SOC were positively correlated with the numbers of TNE, bacterivores of cp-1, 2, 3 guilds, fungivores of cp-2, 4 guilds, omnivores of cp-5 guilds, herbivores of cp-2 guilds and the values of H′. The contents of Total-N were positively correlated with the numbers of TNE, bacterivores of cp-1, 2, 3 guilds, fungivores of cp-2, 4 guilds, omnivores of cp-5 guilds, herbivores of cp-2 guilds and the values of H′, and negatively with the values of MMI. The concentration of N-NO$_3^-$ was positively correlated with the numbers of TNE, bacterivores of cp-1, 2, 3, fungivores of cp-4 and omnivores of cp-5 guilds, the values of H′ and BI, and negatively with the values of MMI and SI (Table 5).

4 Discussion

4.1 Effects of wetland reclamation on soil properties

Different types of wetland exploitation changed the soil physical and chemical parameters significantly (Table 1). The SOC and Total-N were lower in TW compared with CW and GW, and the contents of N-NO$_3^-$ were higher in CW than those in TW and GW. The contents of SOC, Total-N and N-NO$_3^-$ were different in the treatments may be resulted from two factors: the first one is that more abundant over ground coverage afford more addition of plant residues to soils, which caused the increase of soil organic matter and the total nitrogen (Malhi *et al*., 2006); the second factor is the application of fertilizer increased the N-NO$_3^-$ concentration in CW (Sainju *et al*., 2007). The values of pH had no significant differences among the treatments. Compared with GW and TW, the lower values of electrical conductivity (EC) in CW indicated that the drainage of cropland in

Table 3 Changes in abundances (individuals per 100 g dry soil) of nematode functional guilds among different treatments at different sampling depths

Guild^a	Treatment	Sampling depth (cm)					Effect	
		0–20	20–40	40–60	60–80	80–100	Treatment	Depth
Ba$_1$^{b}	GW	0±0B	1±1A	0±0A	0±0A	0±0A	**	**
	TW	0±0B	0±0A	0±0A	2±1A	0±0A		
	CW	80±25A	4±1A	4±2A	1±1A	2±2A		
Ba$_2$	GW	7±2B	7±2A	2±0A	1±0A	0±0A	**	**
	TW	11±2B	10±2A	1±0A	1±1A	1±1A		
	CW	203±56A	14±2A	6±3A	2±1A	6±3A		
Ba$_3$	GW	0±0B	0±0A	0±0A	1±0A	0±0A	*	NS
	TW	0±0B	0±0A	0±0A	0±0A	0±0A		
	CW	6±4A	0±0A	2±0A	0±0A	0±0A		
Fu$_2$	GW	1±1B	1±1B	1±1A	1±0A	1±0A	*	*
	TW	0±0B	0±0B	1±0A	0±0A	0±0A		
	CW	41±22A	4±2A	2±0A	2±1A	1±0A		
Fu$_4$	GW	0±0B	16±3A	6±3A	1±0A	1±1A	**	**
	TW	0±0B	1±0B	0±0B	0±0A	0±0A		
	CW	52±4A	1±1B	2±1B	2±1A	0±0A		
Om$_4$	GW	0±0A	0±0A	0±0B	0±0A	1±0A	NS	NS
	TW	0±0A	0±0A	0±0B	0±0A	0±0A		
	CW	0±0A	0±0A	1±1A	0±0A	0±0A		
Om$_5$	GW	1±1B	8±1A	5±3A	2±1A	1±1A	*	*
	TW	0±0B	1±0B	0±0A	1±1A	0±0A		
	CW	15±5A	0±0B	2±0A	0±0A	1±1A		
H$_2$	GW	3±1B	105±36A	39±13A	55±20A	34±12A	**	NS
	TW	3±1B	13±4B	4±2A	2±1A	0±0A		
	CW	112±43A	9±1B	18±13A	7±4A	5±3A		
H$_3$	GW	41±3A	162±25A	163±5A	26±9A	30±14A	**	**
	TW	26±2B	50±13B	35±4B	47±23A	17±2A		
	CW	74±42A	27±1B	46±18B	24±13A	7±4A		

Notes: Mean values and standard error of three replicates are presented. Different uppercase letters in same column indicate significant differences of variable means among different treatments for each soil depth ($P < 0.05$). a, functional guilds of soil nematodes characterized by feeding habits and life-history characters; b, numbers following the functional groups represent the *cp* values (Bongers and Bongers, 1998; Ferris *et al*., 2001). Ba, bacterivores; Fu, fungivores; Om, Omnivores; H, plant-parasites; GW, grass wetland; TW, tamarix chinensis wetland; CW, crop wetland. **, $P < 0.01$; *, $P < 0.05$; NS, non-significant ($P > 0.05$)

salt marshes can decrease the salinity of soil efficiently (Montemayor *et al*., 2008). In conclusion, the differences in soil properties among the types of wetland might exert a direct or indirect influence on nematode populations via overground vegetation or belowground microbial activity (Zhou, 2001; Ferris and Matute, 2003; Wang *et al*., 2004; Liang *et al*., 2005).

4.2 Effects of wetland reclamation on total nematodes

In general, nematode communities or ecological indices reflected the differences between undisturbed and human-impacted environments. Results in present study showed that the different types of wetland-use have significant effects on the total number of nematodes. At the depth of 0–20 cm the numbers of TNE in CW were significantly higher than those in GW and TW. This may be due to the application of synthetic fertilizer and the disturbance in cropland. These results were in accordance with those of Ettema and Bongers (1993) and Fu *et al*. (2000) which were found that the TNE increase in number as a result of increasing microbial activity caused by, for example, the increased supply of fertilization and other disturbances in the farmland may

Table 4 Changes in the values of nematode ecological indices among different treatments at different sampling depths

Indices	Treatment	Sampling depth					Effects	
		0–20 cm	20–40 cm	40–60 cm	60–80 cm	80–100 cm	Treatment	Depth
H′	GW	1.10±0.06B	1.44±0.22A	1.36±0.08A	1.31±0.18A	0.99±0.30AB	**	*
	TW	1.29±0.06B	1.57±0.15A	1.39±0.02A	0.92±0.14A	0.70±0.40B		
	CW	2.04±0.17A	1.78±0.12A	1.77±0.14A	1.40±0.34A	1.56±0.29A		
J′	GW	0.56±0.01B	0.65±0.08A	0.64±0.04A	0.64±0.10A	0.55±0.11B	**	NS
	TW	0.80±0.03A	0.78±0.03A	0.75±0.00A	0.67±0.03A	0.69±0.03AB		
	CW	0.81±0.04A	0.77±0.04A	0.72±0.06A	0.73±0.05A	0.82±0.04A		
GR	GW	1.51±0.03AB	1.59±0.10B	1.45±0.07B	1.63±0.18A	1.24±0.20AB	**	NS
	TW	1.08±0.05B	1.54±0.26B	1.47±0.05B	0.87±0.01B	1.19±0.11B		
	CW	1.83±0.29A	2.20±0.06A	2.58±0.14A	1.81±0.52A	1.93±0.54A		
MMI	GW	2.83±0.02A	2.79±0.12A	2.93±0.06A	2.43±0.12B	2.61±0.19AB	**	NS
	TW	2.66±0.03A	2.69±0.08A	2.95±0.06A	3.01±0.05A	2.91±0.09A		
	CW	2.25±0.02B	2.43±0.02B	2.70±0.02A	2.70±0.14AB	2.31±0.33B		
SI	GW	47±3A	87±7A	96±2A	86±3A	64±32A	**	**
	TW	5±1B	46±1B	89±2A	86±4A	7±2B		
	CW	57±3A	22±0C	79±5A	71±2A	52±27A		
EI	GW	13±0B	28±20B	11±1C	42±5A	50±0A	**	NS
	TW	3±1C	8±3C	25±14B	50±29A	25±3B		
	CW	57±11A	52±0A	67±6A	64±5A	38±20AB		
BI	GW	49±3B	13±7B	4±2B	13±2A	19±16B	**	**
	TW	96±5A	54±1A	10±2A	7±4B	75±3A		
	CW	27±6C	42±1A	14±3A	19±3A	23±8B		

Notes: Mean values and standard error of three replicates are presented. Different uppercase letters in same column indicate significant differences of variable means among different treatments for each soil depth ($P < 0.05$). GW, grass wetland; TW, tamarix chinensis wetland; CW, crop wetland; H′, Shannon-Weaver diversity index; J′, Pielou evenness index; GR, generic richness; MMI, combined MI; SI, structural index; EI, enrichment index; BI, basal index. **, $P < 0.01$; *, $P < 0.05$; NS, non-significant ($P > 0.05$)

Table 5 Correlation between nematode faunal index and functional guilds with soil physical and chemical parameters

	pH	EC	SOC	Total-N	N-NO_3^-
TNE	0.090	–0.158	0.557**	0.653**	0.360*
H′	0.089	–0.164	0.470**	0.446**	0.376*
J′	0.121	–0.136	0.089	0.143	0.218
GR	0.090	–0.256	0.291	0.258	0.280
MMI	–0.279	0.041	–0.215	–0.348*	–0.314*
SI	–0.366*	–0.161	–0.064	–0.133	–0.332*
EI	0.288	–0.406**	–0.088	0.046	–0.045
BI	0.262	0.390**	0.121	0.146	0.387**
$Ba^{a}_{1}{}^{b}$	0.320*	–0.197	0.482**	0.571**	0.350*
Ba_2	0.287	–0.157	0.528**	0.678**	0.622**
Ba_3	0.215	–0.176	0.368*	0.513**	0.420**
Fu_2	0.280	–0.170	0.361*	0.485**	0.226
Fu_4	0.208	–0.195	0.533**	0.655**	0.414**
Om_4	–0.065	–0.150	–0.128	–0.069	–0.021
Om_5	0.096	–0.131	0.460**	0.558**	0.366*
H_2	–0.096	–0.110	0.393**	0.476**	0.234
H_3	–0.230	0.003	0.264	0.166	–0.165

Notes: TNE, number of TNE; H′, Shannon-Weaver diversity index; J′, Pielou evenness index; GR, generic richness; MMI, combined maturity index. SI, structural index; EI, enrichment index; BI, basal index; a, functional guilds of soil nematodes characterized by feeding habits and life-history characters. Ba, bacterivores; b, numbers following the functional groups represent the *cp* values; Fu, fungivores; Om, Omnivores; H, plant-parasites; EC, electric conductivity; TOC, total organic carbon; Total-N, total nitrogen; N-NO_3^-, nitrate nitrogen (Bongers and Bongers, 1998; Ferris *et al*., 2001). **, $P < 0.01$; *, $P < 0.05$

stimulate the population of nematodes. At the other depths of soil, the numbers of TNE in GW were significantly higher than those in CW and TW, this result indicated that the fertilizer applications and tillage regimes in cropland stimulated the nematodes abundance mainly in the rhizosphere, whereas, below the 20 cm depth, the discrepancy of nematodes abundance might be caused by the *Paratylenchus* genus. *Paratylenchus* has a relatively shorter life cycle; more generations per year would be expected (Verschoor *et al.*, 2001). Geraert (1965) reported that *Paratylenchus* populations may be undetectable in superficial samples but only presented in significant numbers at depth in an Italian field.

Nematode richness, as indicated by the number of genera (Ekschmitt *et al.*, 2001), reflects the biodiversity of soil habitats. In this study, the numbers of nematode genera were significantly higher in CW and GW compared with TW (Table 2). This result was expected as more inputing of fertilization and management stimulated the diversity of soil fauna in CW, and most soil microorganisms and microarthropods occur in top 20 cm of the soil profile (Coulson *et al.*, 1995; Rey *et al.*, 2002). Whereas in GW, significant higher number of nematodes genera indicated that grass wetland with more groundcover vegetation often support the most diverse assemblages of nematodes, possibly as a result of a greater heterogeneity of resources, added during the return of residues and root-exudates (Ou *et al.*, 2005). It is generally accepted that undisturbed systems have more diverse communities of soil organisms (Kandji *et al.*, 2001). This reflects a higher diversity that is derived from greater basal resource inputs. The results suggested that different types of wetland exploitation could affect the biodiversity of soil nematodes. The number of TNE was positively correlative with the contents of SOC, Total-N and N-NO_3^-, but no significant correlations between TNE and the values of pH were noted during the course of this study. So far, the effects of soil pH and EC on the nematodes have not got the consistent results. Some researchers believed that the pH have no significant effects on the nematodes, Mai and Harrison (1959) reported that in the range of potato pH, changes of pH had no effects on the *Globodera rostochiensis* giving damage to potato (Freckman, 1978). Bird (1959) observed that the *Meloidogyne javanica* was not affected by pH ranged from 3.0 to 10.6.

4.3 Effects of wetland reclamation on functional guilds

Different types of wetland reclamation could indirectly affect the composition of soil nematode communities through shifts in the quantity and quality of plant litter returned to soil, the rate of root turnover, and the exudation of carbon and other nutrients into the rhizosphere. The data obtained in the present study indicated that wetland reclamation had significant effects on the abundance of plant-feeding nematodes, the proportions of plant-feeding nematodes were GW (91.0%) > TW (88.1%) > CW (53.5%) (Table 2). Similar results were found by Wu *et al.* (2008) who observed the plant parasite nematodes were the most abundant trophic groups in wetland soils, and the average relative abundance was 91.33% of the nematode community. Plant parasite and omnivore-predator nematodes were more sensitive to the ecophysiological individual features of observed plants versus the total number of nematodes and bateria- and fungi-feeding nematodes (Stanislav *et al.*, 2008), which can explain the changes of soil nematode communities composition in the different types of wetland soils.

Guild designation of nematodes provides a basis for higher resolution interpretation of food web and environmental condition based on similar trophic function and life-history strategy (Ferris *et al.*, 2001). In our study, the wetland reclamation resulted in a replacement of soil nematode functional guilds. The relative abundance of *Protorhabiditis* and the numbers of *Acrobeloides*, which belonging to cp-1 guilds and cp-2 guilds respectively, increased in GW and CW in comparison with the control (Table 2). Since the application of organic and synthetic soil fertility is responsible for the high microbial activity, and congruent with high nitrogen mineralization (Wasilewska, 2006). The *Protorhabiditis* is a typical bacterivorous enrichment opportunistic nematode of cp-1 guild and can indicate the soil fertility status according to Bongers and Ferris, 1999 and Ferris *et al.*, 2001. Our results also support the theory of Forge and Simard (2001) that the Rhabditida showed the positive reaction to nitrogen mineralization. Except the numbers of omnivores of cp-4 guilds, all the numbers of the nematode guilds identified were significantly higher in the 0–20 cm depth of CW than those in GW and TW, while in the other depths the numbers of herbivores belonging to cp-2, 3 guilds and omnivores belonging to cp-5 guilds were higher in GW than those in TW and CW (Table 3). This result is supported by other studies (Ferris *et al.*, 1996; Okada and Ferris, 2001), who reported that in a large temporal scale, the fertilizer applications increase the abundance of general-opportunist bacterivorous and fungivorous nematodes (e.g., Cephalobidae and Aphelenchidae) which have longer life cycles and lower fecundity slowly. Forge and Simard (2001) found that bacterivores and fungivores was positive correlated with the nitrogen mineralization rate. The obtained results indicated that the fertilizer application and tillage managements could provide enough food resources for the soil food web for a long period by stimulating root and/or microbial growth. In addition, the prevalence of bacterivores and fungivores might stimulate the abundance of plant-parasites, which were usually related to primary production and plant susceptibility, bacterial and fungal populations or a combination of these factors (Jiang *et al.*, 2007), and the numbers of omnivores as well as predatory nematodes.

4.4 Effects of wetland reclamation on ecological index

Among the ecological indices tested, evenness (J′) and richness (GR) were effective in distinguishing the differences ($P < 0.05$) among the GW, TW and CW at the each depth in our investigation. Greater J′ and GR values indicated a complex community structure with relatively more linkages in the food web in the crop wetland. The Shannon index (H′) gives more weight to rare species, and a higher index indicates greater diversity. In the present study, the values of H′ were significantly higher in CW than those in GW and TW, which tested that the biodiversity of nematodes in CW was high due to input of fertilization. In addition, the H′ was significantly positively correlated with SOC, total nitrogen and $N\text{-}NO_3^-$. The MMI is modified from nematode maturity index (MI) of Bongers (1990) to include plant feeding nematodes and thus better monitors ecosystem development, lower MMI values indicating more disturbed environments (Yeates, 1994). In our study, the values of MMI exhibited a decreasing trend at each depth, where GW > TW > CW. These results may because of the disturbance caused by reclamation, tillage and fertilization. Similar results were recorded by Ferris *et al.* (1996) for conventional and organic farming systems in California. Lower maturity of organic plots after incorporation of organic material was associated with relatively higher proportions of opportunistic nematodes responding to bacterial blooms and maturity indices seem to offer better prospects for detecting and sufficiently illustrating changes in the soil environment (Bongers, 1990; Yeates, 1994).

The SI is primarily determined by omnivorous and predatory nematode populations, which are sensitive to disruption and need much more time to establish compared to more rapidly growing fungi- and bacteria-feeding nematodes (Ferris *et al.*, 2001). In the present study, the values of SI were higher in GW and lower in CW at each depth of soil, except in the 0–20 cm depth. Higher values of SI indicated a complex community structure with many linkages in the food web (Berkelmans *et al.*, 2003). These results are in agreement with Ferris *et al.* (2001), who observed that SI is always higher in the undisturbed natural systems than that in annual cropping systems, even when these are managed organically. The EI provides an indicator of resources available to the soil food web and the response of primary decomposers to those resources (Ferris *et al.*, 2001). In our study, the EI values were higher in CW than those in GW and TW, which was consistent with the findings of Liang *et al.* (2009) who reported that providing enough food resources for the soil food web positive correlate with the values of EI due to stimulating root and/or microbial growth. These results suggested that the food web in CW treatments progressively developed along an enrichment trajectory. The combination of these two indices (SI and EI) provides a powerful basis for assessing the structure of soil food web and nutrient availability. Higher SI values (> 50) and lower EI values (< 50) suggested more structured as well as little disturbed soil food web in GW; lower BI values (< 50) and lower EI values (< 50) indicated that the food web in TW was stressed; and the enrichment soil food web in the CW was presented by higher BI values (< 50) and higher EI values (< 50) (Ferris *et al.*, 2001). Our results demonstrated that the different types of wetland reclamation were likely to affect below-ground soil ecological processes, which could be monitored by the change of the composition of soil nematode community.

5 Conclusions

In conclusion, soil nematode fauna were significantly affected by wetland reclamation. Nematode community measures were useful in providing the information about the status and processes of the wetland soil ecosystem. They could reflect ecosystem differences imposed by different reclamation forms. A majority of nematode genera, functional guilds and ecological indices could indicate the changes in soil ecosystem processes caused by exploring practices. To accurately characterize the status and processes of the soil ecosystem impacted by human-induced disturbance, we suggest the use of nematode community description at the generic (if not species) level, and long-term studies are necessary to assess the impacts of perturbation on soil processes and biodiversity.

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