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Effects of tillage and residue management on soil nematode communities in North China

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ABSTRACT

Soil nematode abundance, community composition and biomass were determined in the Fengqiu State Key Agro-Ecological Experimental Station, North China, in order to evaluate the effects of tillage system (conventional tillage and no-tillage) and residue management (0, 50% and 100% wheat residue incorporation/coverage) on the nematode communities. Two kinds of indicators (descriptive and evaluative) were categorized. Of the descriptive indicators, residue management had a significant effect on the total nematode abundance, biomass and trophic groups except for bacterivores. Of the evaluative indicators, Shannon diversity (H′), generic richness (GR), nematode channel ratio (NCR) and enrichment index (EI) significantly increased with increasing residue quantity, whereas dominance (λ), basal index (BI) and channel index (CI) exhibited an opposite trend. Significant tillage effects were observed on the trophic diversity (TD), EI, CI and carbon production (*P*). The responses of nematodes to tillage and residue were genus-dependent. Canonical correspondence analysis indicated that tillage explained 4.9% and 15.4%, and residue management explained 5.2% and 13.1% of the variations in soil nematode abundance and biomass, respectively. Different metabolic footprint characteristics of the food web were demonstrated graphically by enrichment and structure footprints. The evaluative indicators, such as EI and CI, were sensitive to both tillage and residue management. The descriptive indicators could be used to obtain an intuitive answer to the effect of residue management and the evaluative indicators were more comprehensive for interpreting the structure and function of the soil food web under different tillage and residue management regimes.

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1. Introduction

In agroecosystems, tillage and residue management as main agricultural practices (Minoshima et al., 2007) could affect the surface residue accumulation, leading to changes in soil physiochemical properties, microbial activity and biomass, and further resulting in profound changes in the composition and function of soil biota (Ferris et al., 2004; Liebig et al., 2004). There were many soil properties to changes in management practices, some of which were highly sensitive, whereas others were more subtle (Bezdicek et al., 1996; Mendoza et al., 2008). The chemical or physical measures might therefore be not enough for detecting potential changes in an ecosystem (Suter II, 2001). Practical assessment of soil quality requires considering biological factors. More researchers have realized the need to measure environmental conditions using biological rather than physicochemical indicators (Goodsell et al., 2009).

According to the definition of bioindicators, two kinds of indicators (descriptive and evaluative) can be categorized (Heink and Kowarik, 2010). Descriptive indicators were used to reflect attributes of the indicators and describe the state or analyze changes in agroecosystems (McGeoch, 1998; Walz, 2000). Evaluative indicators served mainly for evaluating ecosystem function and diagnosing the cause of an environmental problem (Dale and Beyeler, 2001). Soil nematode communities have been widely used as bioindicators of ecosystem conditions (Yeates, 2003; Ritz et al., 2009; Sánchez-Moreno et al., 2010), due to their key positions in soil food webs (Neher, 2001). The utilization of nematode community analysis for indicating soil food web dynamics in agroecosystems has been reported by many researches (Wardle et al., 1995; Ferris and Matute, 2003; Briar et al., 2007; Sánchez-Moreno et al., 2008; DuPont et al., 2009). As descriptive indicators, nematode abundance, body length and biomass are relatively easy to determine and their increase or decrease are usually directly

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Table 1
Total abundance and biomass of soil nematodes and abundance of trophic groups (mean ± SE) in the different tillage and residue treatments.

Tillage	Residue	Total abundance[a]	Total biomass[b]	BF[a]	FF[a]	PP[a]	OP[a]
NT	0	2441.39 ± 264.03	66.65 ± 32.00	279.47 ± 27.99	240.72 ± 50.55	1773.38 ± 214.70	147.83 ± 18.85
	50	2384.80 ± 144.34	55.15 ± 19.24	341.28 ± 45.27	197.98 ± 31.23	1682.11 ± 96.27	163.44 ± 53.43
	100	2984.61 ± 350.51	116.50 ± 37.77	378.32 ± 58.82	252.00 ± 56.43	2083.17 ± 288.11	271.12 ± 104.11
CT	0	2450.86 ± 262.19	39.38 ± 21.41	369.76 ± 55.21	428.66 ± 87.52	1541.67 ± 134.90	110.78 ± 32.74
	50	2476.88 ± 466.71	64.87 ± 28.47	466.29 ± 105.34	170.13 ± 55.31	1628.22 ± 308.19	212.24 ± 43.84
	100	3431.26 ± 320.25	90.86 ± 22.82	478.09 ± 67.76	253.45 ± 55.71	2381.66 ± 260.24	318.07 ± 74.96
Tillage		ns	ns	ns	ns	ns	ns
Residue		<0.05	<0.01	ns	<0.05	<0.05	<0.05
Tillage × Residue		ns	ns	ns	ns	ns	ns

[a] Individuals per 100 g dry soil.
[b] μg per 100 g dry soil.

affected by tillage and cover crops (Fiscus and Neher, 2002; Ferris, 2010; Mills and Adl, 2011). Wardle (1995) summarized that there were different responses (stimulation or inhibition) of total nematode abundance to tillage in different studies and larger organisms were likely to be reduced by tillage. DuPont et al. (2009) found that plant parasites were increased and omnivores-predators did not vary significantly in cover crop treatments. Significant increase in the body length of nematode families such as Dorylaimidae, Monhysteridae and Cephalobidae were observed in an intensive management system (Mills and Adl, 2011). As evaluative indicators, some nematode ecological indices have been proven to be useful tools for evaluating soil conditions. Lenz and Eisenbeis (2000) found that nematode trophic diversity (TD) did not indicate the tillage disturbance, but the maturity index (MI) was suitable for indicating immediate tillage effects on the nematode community. Cover-cropped soils had a high enrichment index (EI) and low channel (CI) and basal (BI) indices, suggesting a bacterial-dominated food web under nutrient enrichment conditions (DuPont et al., 2009). Ferris et al. (2001) confirmed a more structured food web in a conventional management system by using nematode community structural indices. Using metabolic footprints, Ferris (2010) monitored the metabolic activity of different nematode guilds in the farming system with crop coverage, and found that the metabolic footprints provided more detailed interpretation on the structure and function of the soil food web.

The objectives of our study were to determine the effects of tillage and residue management on the nematode communities and soil food webs, and to evaluate the bioindication validity of different nematode-based indicators to different tillage and residue management regimes.

2. Material and methods

2.1. Study site

The experiment was set up in the Fengqiu State Key Agro-Ecological Experimental Station (35°01′N, 114°32′E), Henan province, located in the Huang-Huai-Hai Plain of China in 2007. The 30-year mean annual temperature in the area was 13.9 °C, and the annual precipitation ranged from 355 mm to 800 mm (Ding et al., 2010). The rotation of summer maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) was practiced for at least 50 years before the experiment was established. The soil is calcareous (Fluvo-Aquic soil) with 11.13 g/kg organic matter, total nitrogen 1.39 g/kg, pH (H_2O) 8.24 and bulk density 1.16 g/cm^2 (Cai and Qin, 2006; Zhu et al., 2009).

2.2. Experimental design and soil sampling

The experiment was a split-plot design with six replicates. Tillage system was the main plot factor and residue management the sub-plot factor. The tillage systems were conventional tillage (CT) and no-tillage (NT). Chopped wheat residues were incorporated into soil in the conventional tillage field and covered the soil surface in the no-tillage field. Three residue treatments were 0 (no wheat residue incorporation/coverage), 50% and 100% (7.5 t/ha) wheat residue incorporation/coverage. Individual plots were 4 m wide and 100 m long for convenient in-field agronomic operation. Thirty-six soil samples were collected from the 0 to 20 cm depth before harvesting wheat on June 10, 2010. Composite samples of 5 random sub-samples per plot were collected with a 2.5 cm diameter auger. The fresh samples were stored at 4 °C until analysis.

2.3. Soil nematode determination

Nematodes were extracted from 100 g of fresh soil by a modified cotton–wool filter method (Liang et al., 2009). Nematode abundance was expressed as individuals per 100 g dry soil and at least 100 nematodes from each sample were identified to genus level using an inverted compound microscope, according to Jairajpuri and Ahmad (1992) and Bongers (1994). Following identification, the nematode length (μm) and maximum body diameter were determined using an ocular micrometer. The nematodes were assigned to the following trophic groups characterized by feeding habits: bacterivores (BF), fungivores (FF), plant parasites (PP) and omnivores-predators (OP) (Steinberger and Loboda, 1991; Yeates et al., 1993).

2.4. Data analysis

The ecological indices for soil nematodes were calculated: trophic diversity (TD) for trophic groups (Wieser, 1953), Simpson's dominance index (λ) (Simpson, 1949), Shannon diversity (H′) (Shannon, 1948) and richness (GR) (Yeates and King, 1997) for genera, maturity index (MI) (Bongers and Ferris, 1999), and nematode channel ratio (NCR) (Yeates and Bongers, 1999). Enrichment (EI), structure (SI), basal (BI) and channel (CI) indices were calculated from weighted faunal components (Ferris et al., 2001).

Nematode biomass was calculated by the formula $W = (L^3/a^2)/(1.6 \times 10^6)$, where W is the fresh weight (μg) per individual, L is the nematode length (μm), and a is the length to maximum body diameter ratio. Carbon respiration coefficient, $R = 0.273(W^{0.75})$; carbon production, $P = 0.1W_t/m_t$, where W_t and m_t are the body weight and the cp class of taxon t. The metabolic footprint calculation, $F = P + R$. The enrichment (efoot) and structure footprint (sfoot) are the metabolic footprint of lower (cp1–2) and higher (cp3–5) trophic levels, respectively (Neher et al., 2004; Ferris, 2010).

Canonical correspondence analysis (CCA) was performed to explore the nematode community in relation to tillage and residue management using the CANOCO software (ter Braak and Šmilauer,

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