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Effects of Tillage Practices on Soil Enzyme Activities and Nematode Communities During the Growth of Maize (*Zea may* L.)

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Abstract: A field experiment was carried out at the Shenyang Experimental Station of Ecology (CAS) in order to determine the effects of conventional tillage (CT), no-tillage (NT) and fallow on soil enzyme activities and nematode communities in an aquic brown soil during the maize (*Zea may* L.) growing season. The results showed that activities of invertase, urease, acid phosphatase, arylsulfatase and dehydrogenase were significantly higher under NT than under CT across different growth stages. The numbers of total nematodes were higher under NT than under CT during the maize growing season. The numbers of fungivores were significantly higher under CT than under NT at the seedling stage. The higher values of nematode channel ratio (NCR) under NT than under CT indicated that the bacterial decomposition pathway was relatively more dominant under CK and NT, while the fungal decomposition pathway was more important under CT. The numbers of total nematodes and plant parasities were positively correlated with total C and total N. Activities of acid phosphatase and arylsulfatase were positively correlated with total nematodes, bacterivores and plant parasites. Our results indicated that NCR was a good indicator to reflect differences in decomposition pathway or channels under different tillage practices.

Key words: Enzyme activities · nematode communities · fallow · conventional tillage · no-tillage · aquic brown soil · maize growing season

INTRODUCTION

Cultural practices such as tillage affect soil abiotic and biotic factors, which in turn may influence soil enzyme activities and nematode communities [1, 2]. Conservation tillage is a favorable soil management practice because it can minimize soil disturbance, reduce soil erosion and chemical fertilizer use and prevent soil organic matter losses [3, 4]. As a common conservation practice, no-tillage (NT) proved to be superior to conventional tillage (CT) [5]. Adoption of no-tillage can protect soils from biological degradation and maintain soil quality [6].

Soil enzymes play an important role in the reactions of organic matter decomposition and nutrient cycling [7]. Soil enzyme activities have been suggested as potential indicators of soil quality because of their essential role in soil biology, ease of measurement and rapid response to changes in soil management [8]. In general, soil enzymes, microbial biomass and soil organic matter were significantly greater in surface no-till soils than in plowed soils, while a reverse trend in deeper layers was observed [9, 10]. Moreover, some enzyme activities have been found increased under NT with crop residues over the soil, including acid phosphomonoesterase, arylsulphatase, dehydrogenase, urease and β-glucosidase [11, 12].

Soil nematode communities can provide unique insight into many aspects of soil processes. Because most nematodes are active in soil throughout the year, they can provide a holistic measure of the biotic and functional status of soils [13]. Any soil disturbance can affect soil nematode trophic structure and total abundance. In agroecosystems, tillage is the major disturbance to soil and it causes the redistribution of plant residue and soil organic matter, subsequently changing microbial structure and nematode trophic structure [2]. Total numbers of nematodes may either be enhanced or reduced by tillage, regardless of whether corresponding NT treatments are under a similar annual or perennial cropping regime. Moreover, the numbers of bacterivores and fungivores can demonstrate positive or

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negative responses to tillage [14]. However, all nematode trophic groups were significantly higher in NT than in CT in an American field study [13].

Little information is available concerning the tillage effects on soil enzyme activities and nematode communities in China. The objective of this study was to determine the effects of conventional tillage (CT), no-tillage (NT) and fallow on soil enzyme activities and nematode communities during the growth of maize (*Zea may* L.) in an aquic brown soil, Northeast China.

MATERIALS AND METHODS

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 established in 1990. The station is located in the continental temperate monsoon zone, with a dry-cold winter and a warm-wet summer. Mean annual temperature is 7.0-8.0°C; annual precipitation averages 650-700 mm and the annual non-frost period is 147-164 days. The soil at the study site is classified as an aquic brown soil (silty loam Hapli-Udic Cambosol in the Chinese Soil Taxonomy) [15]. Three treatments were implemented since 2003, including fallow field (CK), conventional tillage (CT) and no-tillage (NT). Each treatment under CT and NT was with three plots of approximately 102 m^2. An adjacent fallow field was sampled as control (CK), dominated by grasses including *Ambrosia trida* (Li.), *Conyza canadensis* (L.), Cronquist *Humulus scandens* (Lour.) Merr. and *Metaplexis japonica* Makino. The CT plots were strip planted with maize (*Zea mays* L.) and performed rotary plowing to a depth of 15 cm every spring. Maize was planted in late April and harvested in late September during the rainy season and fertilized with 300 kg N ha^{-1}, 150 kg P ha^{-1} and 75 kg K ha^{-1} before maize sowing. Weeds were controlled by spraying 9 kg ha^{-1} of atrazine and acetochlor (ratio of 1: 1) in early May. NT plots received the same rates of the agrochemicals and 22.89×10^3 kg ha^{-1} of residues from the previous crop. The soil physicochemical properties under different treatments were shown in Table 1.

Sampling, extraction and identification of soil nematodes: Samples were collected from each plot at the 0-10 cm depth on May 31 (seedling stage), June 25 (jointing stage), July 17 (male tetrad stage), August 19 (filling stage) and September 24 (ripening stage) in 2005. Each sample comprised of five soil cores (5 cm in diameter) was placed in an individual plastic bag and then stored immediately in a 4°C cold room. A subsample (100 g) of each sample was taken for nematode exaction by elutriation and sugar-centrifugation [16-17]. All extracted nematodes in each sample were counted and expressed individuals per 100 g dry weight soil. 100 nematodes per sample were selected randomly and identified to genus. The classification of trophic groups was assigned to: 1) bacterivores, 2) fungivores, 3) plant-parasites and 4) omnivores-predators based on known feeding habits or stoma and esophageal morphology [16-19]. The ecological index nematode channel ratio (NCR) is a powerful ecological index and reflects differences in decomposition pathways or channels between differing management regimes. NCR is expressed as: NCR = BF/(BF+FF) [20].

Soil physicochemical and biochemical measurements: Before analysis, soil samples were air-dried, ground to pass through a 2 mm sieve for determination of soil physicochemical properties. Soil total C was analyzed by dry combustion, using a Shimadzu TOC 5000 Total C analyzer. Soil total N was determined by Kjeldahl digestion, followed by NaOH distillation and measured by titration with 25 mM H_2SO_4 in boric acid indicator [17]. Soil pH was measured in a 1:2.5 (soil:water) slurry using a glass electrode. Soil electrical conductivity (EC) was determined in a 1:5 (soil:water) using Thermo Orion 150 A+. Bulk density was calculated from dry soil weights (105 °C, 48 h) and the volume of samples taken with a hammer-driven core sampler [12]. Activities of dehydrogenase (E.C. 1.1; triphenyl formazan release method; 37°C); acid phosphatase (acid phosphomonoesterase, EC 3.1.3.2; pH 6.5, 37°C); urease (urea amidohydrolase, EC 3.5.1.5; urea residue method; 37°C) and arylsulfatase (arylsulfatase sulfohudrolase, EC 3.1.6.1; pH 5.8, 37°C) were assayed as described by Tabtabatai [21]. Invertase

Table 1: Soil physicochemical properties under different tillage practices (means ± SD)

Treatment	Total C (g kg^{-1})	Total N (g kg^{-1})	C/N	pH	EC (ms cm^{-1})	Bulk density (g cm^{-1})
CT	13.31±2.82a	1.08±0.07b	12.32±0.62a	5.35±0.05b	102.73±15.34a	1.03±0.01b
NT	13.01±2.20a	1.02±0.18b	12.75±0.80a	6.02±0.79a	105.13±10.72a	1.23±0.07a
CK	15.28±1.16a	1.32±0.05a	11.57±0.58a	6.04±0.23a	77.23±20.05a	1.21±0.08a

CT: conventional tillage; NT: no-tillage; CK: fallow field

Values within the same column followed by different letters indicate significant differences ($p<0.05$) between treatments, as determined by Fisher's least significant difference test

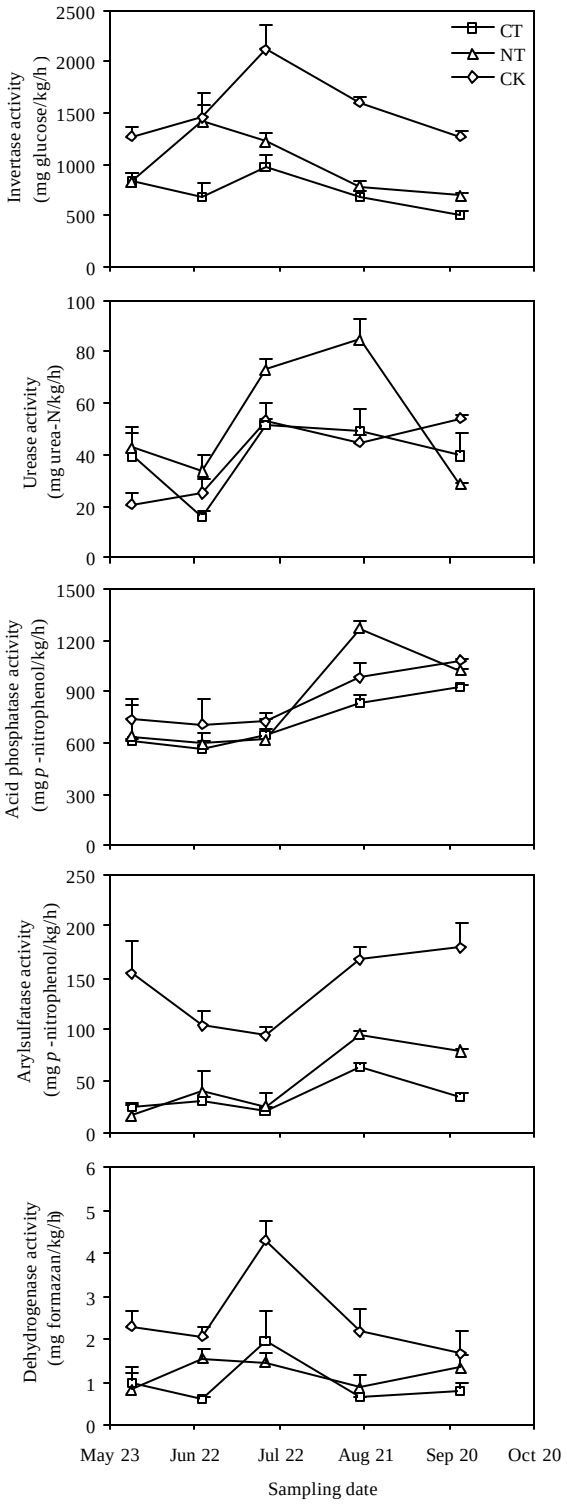

Fig. 1: Dynamics of soil enzyme activities under different tillage practices during the maize growing season (means± SD)

Table 2: Absolute abundance (individuals per 100 g dry soil) of soil nematodes under different tillage practices during the maize growing season (means ± SE)

	Trophic group				
Treatment	TNEM	BF	FF	PP	OP
	Seedling stage				
CT	110.0±24.1b	20.3±4.4a	12.3±0.9a	72.5±17.7b	6.8±1.9a
NT	116.0±45.9b	20.4±1.3a	2.8±1.5b	92.9±45.5b	0.0±0.0a
CK	385.2±89.9a	44.6±19.4a	15.8±3.4a	309.5±80.8a	15.4±9.8a
	Jointing stage				
CT	157.5±50.6a	23.8±11.3a	30.1±4.5a	92.0±26.5ab	11.6±8.4a
NT	113.1±20.9a	21.3±9.7a	15.2±9.2a	73.9±13.5b	10.5±4.2a
CK	231.7±36.9a	31.0±11.2a	22.0±6.8a	171.9±34.6a	6.7±5.4a
	Male tetrad stage				
CT	67.4±11.3a	17.1±3.5a	18.9±7.1a	38.5±4.5a	2.7±1.6a
NT	107.2±10.3a	20.7±8.9a	6.3±3.0a	77.7±3.0a	2.9±1.6a
CK	134.6±33.0a	21.5±3.2a	14.6±5.6a	91.9±28.2a	6.6±3.0a
	Filling stage				
CT	159.8±39.3b	22.4±2.0ab	14.8±11.8ab	108.7±48.5b	13.8±12.4a
NT	190.5±28.6b	18.4±10.2b	4.4±4.4b	128.2±43.5b	6.2±4.6a
CK	1198.1±113.1a	115.2±47.9a	40.7±12.2a	1030.7±111.3a	11.5±7.4a
	Ripening stage				
CT	49.2±17.4c	28.3±20.9b	12.2±9.6a	56.8±36.9b	2.0±0.2b
NT	344.1±93.9b	71.3±13.7b	30.1±17.8a	235.9±101.4b	6.8±3.5b
CK	1076.6±93.1a	239.6±44.1a	19.9±7.9a	782.2±38.1a	34.9±8.1a

CT: conventional tillage; NT: no-tillage; CK: fallow field;

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

Values within the same column followed by different letters indicate significant differences ($p < 0.05$) between treatments, as determined by Fisher's least significant difference test

(β-D-fructofuranoside fructohydrolase, EC 3.2.1.26; 5% sucrose, 30°C) was estimated by the procedures of Parthasarathi [22]. All enzyme activities were determined in duplicate field-moist samples and all data were expressed based on the oven-dry weight of soil.

Statistical analysis: All data were analysed by one-way analysis of variance (ANOVA) with treatment as independent variables. Multiple comparisons were conducted based on LSD. Difference at $p<0.05$ level was considered as statistically significant. All statistical analyses were performed by SPSS software package.

RESULTS

Changes in soil enzyme activities: Soil enzyme activities fluctuated greatly among treatments during the maize growing season (Fig. 1). Urease activity was significantly higher under NT than under CT from the jointing to filling stage ($p<0.05$). Acid phosphatase activity changed slightly in the early stages under different treatments and reached a maximum at the filling stage. Activity of acid phosphatase was significantly higher under NT than under CT at the filling and ripening stages ($p<0.05$) and significantly higher under CK than under CT across the maize growing season (($p<0.05$)). Activities of invertase, dehydrogenase and arylsulfatase were significantly higher under CK than under NT and CT across the growth season ($p<0.05$).

Changes in the numbers of total nematodes and trophic groups: The numbers of total nematodes ranged from 67 to 1198 individuals per 100 g dry soil under different treatments. The numbers of total nematodes were significantly higher under CK than under CT and NT across the seedling, filling and ripening stages ($p<0.05$). Those of total nematodes were significantly higher under NT than under CT at the ripening stage ($p<0.05$) (Table 2).

Bacterivores were found significantly higher under CK than under NT at the filling and ripening stages ($p<0.05$). Fungivores were significantly higher under CK than under NT at the seeding and filling stages ($p<0.05$) and significantly higher under CT than under NT at the seedling stage ($p<0.05$). Plant parasites were observed to

Table 3: Mean relative abundance (%) of soil nematodes under different tillage practices during maize growing season

	Treatment		
Trophic group/Genus	CT	NT	CK
Bacterivores	19.0	18.6	14.7
Acrobeles	0.9	0.4	1.6
Acrobeloides	6.7	7.5	6.2
Chiloplacus	0.8	0.8	1.5
Eumonhystera	0.0	0.0	0.1
Heterocephalobus	3.8	2.0	1.4
Mesorhabditis	3.7	3.3	1.6
Metateratocephalus	0.2	0.5	0.2
Panagrolaimus	0.2	0.7	0.5
Pletus	0.1	0.1	0.5
Prismatolaimus	0.7	0.7	1.0
Protorhabditis	1.9	2.6	0.1
Fungivores	15.3	6.4	5.9
Aphelenchoides	7.3	3.9	1.1
Aphelenchus	6.1	1.8	2.5
Ditylenchus	1.4	0.1	1.5
Pseudhalenchus	0.5	0.6	0.8
Plant-parasites	59.1	71.5	76.0
Boleodorus	0.4	0.2	4.4
Coslenchus	0.0	0.0	0.2
Filenchus	6.1	10.0	10.5
Helicotylenchus	18.9	26.8	38.1
Heterodera	1.6	1.2	0.0
Macroposthonia	3.9	0.4	2.3
Malenchus	0.0	0.1	0.8
Paratylenchus	7.2	9.4	18.4
Pratylenchus	20.6	22.5	0.2
Psilenchus	0.4	0.9	1.1
Omnivores-predators	6.6	3.5	3.4
Aporcelaimellus	0.1	0.8	0.7
Diphtherophora	0.0	0.0	0.1
Dorylaimellus	0.0	0.1	0.0
Epidorylaimus	2.7	0.7	0.4
Eudorylaimus	0.5	0.4	0.3
Mesodorylaimus	1.0	0.0	0.3
Microdorylaimus	0.5	0.8	0.5
Nygolaimus	0.1	0.0	0.0
Thonus	0.0	0.3	0.4
Thornia	0.7	0.1	0.2
Tylencholaimus	1.0	0.3	0.5

CT: conventional tillage; NT: no-tillage; CK: fallow field

Bold values indicate the mean relative abundance of each trophic group

be the most abundant trophic group and their mean relative abundances under CK, CT and NT were 76.0, 59.1 and 71.5%, respectively. The numbers of plant parasites were significantly higher under CK than under CT and NT at the seedling, filling and ripening stages ($p<0.05$). Omnivores-predators were significantly higher under CK than under CT and NT at the ripening stage ($p<0.05$). No significant differences in the numbers of bacterivores, plant parasites and omnivores-predators were observed between CT and NT during the maize growth season.

Nematode genera and ecological index: Thirty-six genera were observed in our investigation. Most genera belonged to bacterivores (11) and omnivores-predators (11), followed by plant-parasites (10) and fungivores (4). *Helicotylenchus* was found to be the dominant genera under different treatments, *Pratylenchus* and *Filenchus* under CT, *Pratylenchus* under NT and *Filenchus* and *Paratylenchus* under CK (Table 3). The values of NCR were higher under NT than under CT (Table 4). The values of NCR were significantly higher under NT than under CT at the seedling and jointing stages ($p < 0.05$).

Correlations of soil nematodes with soil chemical/ biochemical properties: The numbers of total nematodes and plant parasites were positively correlated with total C, total N and activities of invertase, phosphatase and arylsulfatase (Table 5). Positively correlations were also found between bacterivores and phosphatase, arylsulfatase activities. Fungivores were negatively correlated with urease activity and positively with arylsulfatase activity. Omnivores-predators were positively correlated with arylsulfatase activity. In addition, the values of NCR were positively correlated with activities of urease and phosphatase.

DISSCUSION

Soil tillage practices can influence soil microorganisms and enzyme activities through changes in the distribution of soil organic matter in the soil profile [8, 12]. The higher activities of soil enzymes can accelerate soil organic matter turnover and benefit plant growth [5]. In our study, activities of invertase, urease, acid phosphatase, arylsulfatase and dehydrogenase were found to be significantly higher under NT than under CT during the maize growing season ($p<0.05$). These results were consistent with those reported by Kandeler *et al.* in the Lower Austria [8], Roldán *et al.* in central Mexico [9] and Franzluebbers in southcentral Texas, USA [23]. The higher activity of urease under CT and NT than under CK at the seedling stage may be affected by short-term N addition in late April. This result showed that the production of enzymes was greatly affected by N availability [7].

Table 4: Variation of nematode channel ratio (NCR) under different tillage practices during maize growing season (means ± SE)

Treatment	Seedling stage	Jointing stage	Male tetrad stage	Filling stage	Ripening stage
CT	0.61±0.06b	0.40±0.07b	0.50±0.07a	0.71±0.18a	0.69±0.11a
NT	0.89±0.06a	0.64±0.06a	0.74±0.13a	0.83±0.17a	0.74±0.09a
CK	0.68±0.10ab	0.58±0.01ab	0.62±0.10a	0.72±0.08a	0.93±0.01a

CT: conventional tillage; NT: no-tillage; CK: fallow field

Values within the same column followed by different letters indicate significant differences ($p<0.05$) between treatments, as determined by Fisher's least significant difference test

Table 5: Correlation coefficients between soil nematodes and chemical/biochemical properties under different tillage practices

Indicator	Total C	Total N	C/N	Invertase	Urease	Dehydrogenase	Phosphatase	Arylsufatase
TNEM	0.443**	0.442**	0.228	0.317*	0.015	0.160	0.463**	0.804**
BF	0.276	0.277	0.140	0.173	0.030	0.084	0.427**	0.658**
FF	0.082	0.126	-0.074	0.121	-0.332*	0.061	0.071	0.297*
PP	0.444**	0.434*	0.254	0.324*	0.013	0.167	0.438**	0.780**
OP	0.156	0.182	0.027	0.126	-0.019	0.036	0.274	0.527**
NCR	0.126	0.097	0.138	-0.044	0.342*	-0.062	0.425**	0.256

TNEM: total nematodes; BF: bactervores; FF: fungivores; PP: plant parasites; OP: omnivores-predators

*, **: Significant at $p<0.05$ and $p<0.01$, respectively

Agricultural management practices, such as tillage, fertilization, irrigation and pesticide application have been shown to cause disturbance to the soil ecosystem and then affect the soil nematode community structure [2, 14-15, 18]. In our study, the numbers of total nematodes were found to be significantly higher under NT than under CT at the ripening stage ($p<0.05$), which may be due to less disturbance under NT compared to CT. This result was consistent with Lenz *et al.* [24], who reported that nematode density was significantly reduced after tillage.

Plant parasites were observed to be the most abundant trophic group under different treatments. These results coincided with those reported by Ou *et al.* [16], who found plant parasites were the most abundant trophic group in the conventional maize field and fallow field. No significant differences were found in the numbers of bacterivors, plant parasites and omnivores-predators between CT and NT, while fungivores were significantly higher under CT than under NT at the seedling stage ($p<0.05$). These results were inconsistent with those by Fu *et al.* [2], who reported that all trophic groups were significantly higher under NT than under CT at the 0-5 cm soil layer in the field study. The discrepancy may be attributed to the period of no-tillage.

The ecological index nematode channel ratio (NCR) can be used to reflect the decomposition pathway of detritus food web in soil. The relative importance of the fungal pathway often reflected lower rates of decomposition [20]. The obtained values of NCR ranged from 0.30-0.92 with higher values found under CK and NT compared to CT across the maize growing season. The values of NCR indicated the bacterial decomposition pathway was relatively more dominant under CK and NT and played a more important role in nutrient cycling, while the fungal decomposition pathway was relatively more important under CT. Our results were in agreement with those obtained by Fu *et al.* [2], Lenz and Eisenbeis [24].

The numbers of total nematodes and plant parasites were positively correlated with total C and total N. The results were in agreement with those reported by Ou *et al.* under different land uses in the same study site [16]. Significant correlations ($p<0.05$) were also found between soil enzyme activities and nematode communities. Many studies showed that soil nematodes can affect the biomass and activity of the microbial community through their feeding action on fungi and bacteria [25, 26]. And soil enzymes are mainly originated by soil microorganism and are often used as indices of microbial activity and soil fertility [27]. Thus the nematode predation may indirectly affect the soil enzyme activity by changing the microbial biomass and activity [26]. Djigal *et al.* [28] also found that alkaline phosphatase activity was increased by nematode inoculation.

In conclusion, our study showed that no-tillage (NT) improved soil enzyme activities involved in nutrient cycling in the surface soil layer compared to CT. The numbers of total nematodes were higher under NT than under CT. Activities of acid phosphatase and arylsulfatase were positively correlated with total nematodes, bacterivores and plant parasites. The fungal-based food web was relatively more dominated under CT, while bacterial-based food web was more dominant under NT. The ecological index NCR can be used to

reflect differences in decomposition pathway or channels under different tillage practices.

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