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Full Length Research Paper

Effects of banana wilt disease on soil nematode community structure and diversity

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Effects of banana wilt disease caused by *Fusarium oxysporum* f. sp*. cubense* (FOC) on soil nematode community composition were investigated in Hainan province China. The results show that 31 nematode genera in the disease and control regions were identified. The disease area was mainly dominated by *Acrobeles*, *Acrobeloides*, *Chiloplacus* and *Aphelenchus*, while *Pelodera*, *Protorhabditis*, *Ditylenchus* and *Basiria* dominated in the control area. *Paratylenchus* was the dominant genus in both areas. The abundance of total nematodes, bacterivore (10 to 30 cm), plant parasites and omnivores-predators, the values of diversity (H′), maturity index (MI), plant parasite index (PPI), structure index (SI), enrichment index (EI), soil pH, the contents of total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP) and alkaline nitrogen (AN) in the disease area were significantly lower ($P < 0.01$) than in the control. However, those of fungivores (10 to 20 cm) and dominance (λ) exhibited quite a reverse result. In the disease area, the abundance of total nematodes and bacterivore decreased ($P < 0.01$) and plant parasites increased ($P<0.01$) with the increase of soil depth. The values of SI increased ($P <0.01$) with the increase of soil depth in the disease and control areas in 0 to 20 cm. The results indicate that FOC changed soil nematode community characteristics and decreased diversity of soil nematode community.

Key words: Banana wilt disease, *Fusarium oxysporum* f. sp*. cubense* (FOC), soil nematode community, diversity.

INTRODUCTION

Banana (*Musa spp.* L.), the second largest fruit crop in the world, is an important staple food in tropical America, Asia and the Pacific (Poornima et al., 2007). It is one of the most important fruit crops in China and its output is over 9.28 million in 2010 (FAO, 2010). However, the production is seriously threatened by the development of increasingly virulent forms of banana wilt disease (De Waele et al., 2006). Banana wilt disease caused by *Fusarium oxysporum* f.sp. *cubense* (FOC) is currently considered one of the most destructive diseases in certain banana-growing areas in the world, with an annual yield loss up to 60 to 90% in many countries (Bhuvanendra, 2010).

Fusarium oxysporum f. sp. *cubense* (FOC) raises havoc with soil physical, chemical and biological properties. Domínguez et al. (2008) reported that banana wilt disease caused unfavorable soil conditions such as low pH, electrical conductivity, organic matter, soil fertility and high soil compaction. Wu et al. (2009) also observed that soil enzymes activities, soil respiration and microbial biomass were significantly lower in watermelon wilt diseased area compared to un-diseased area. Complex infection caused by plant parasitic nematodes and FOC gave rise to a necrotic and reduced root system, which in turn, resulted in a reduction in the uptake and transportation of water and nutrients by the plant (Poornima et al., 2007). Complex infection of green gram and pigeonpea by fungi inducing *Fusarium* wilt and root-knot

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nematode, *Meloidogyne incognita*, severely restricted plant root growth and decreased annual yield loss by 40 to 80% (Haseeb et al., 2005; Goswami et al., 2007). Yucel et al. (2009) reported that tomato wilt disease was hastened considerably in the presence of *M. incognita* and *Meloidogyne javanica*, which created a food base for *Fusarium oxysporum* and increase their invasive potential.

In order to investigate the effects of pathogen causing banana wilt disease on soil ecosystem in banana plantation, there is a need to develop a set of indicators that are able to quantify changes in soil ecosystem stability and monitor rapid response to various disturbances. Soil nematodes as a component of the soil ecosystem interact with biotic and abiotic soil factors (Hohberg, 2003). Because of this interaction, nematodes are excellent bio-indicators of soil health. They form a dominant group of organisms with high abundance and biodiversity, which play an important role in nutrient recycling within the soil (Neher, 2001; Schloter et al., 2003). Nematodes are heterotrophs in the higher food chain compared to microorganisms and serve as integrators of soil pro-perties and environment disturbance related to their food source, predators and parasites (Ferris, 2010). They show rapid reaction to the disturbance or stress caused by banana wilt disease in temperate and tropical regions (Pattison et al., 2008). Both the classification of soil nematodes into trophic groups and understanding of nematode life strategies, whether colonisers or persisters (c-p), are useful measurement to detect the changes of soil microbial composition in banana wilt disease areas and provide information about the level of disturbance (Berkelmans et al., 2003; Stirling et al., 2004).

FOC enriched soils show a reduced biodiversity. Under such conditions the populations of bacterivores (mainly in Rhabditidae, Pangrolaimidae and Cephalobidae), plant parasites (mainly in Meloidogynidae, Hoplolaimidae, Pratylenchidae and Rotylenchulidae) and omnivores or predators (mainly in Qudsianematidae) decreased in contrast to other nematode groups, while the proportion of fungivores (dominated by Aphelenchidae and Aphelenchoididae) exhibited a reverse condition (Poornima et al., 2007; Quénéhervé, 2008; Duyck et al., 2009). It is accepted that nematodes of certain fauna composition, together with its ecological indices, has emerged as a useful monitor of disturbance or stress soil conditions (Goodsell et al., 2009).

Until now, many researches had reported parasitic nematodes interacted with the fungal wilt disease among various vegetation types and soil types (Haseeb et al., 2006; Goswami and Tiwari, 2007). However, there is little information about using soil nematode as bio-indicators to measure the level of disturbance caused by FOC. The objective of this study is to compare the differences between soil nematodes trophic groups and ecological indices in banana wilt diseased and un-diseased soil and determine how soil chemical and biological properties have been changed due to banana wilt disease. We expect that soil nematodes are useful bio-indicators to measure the effects of FOC on soil ecosystem health of banana plantation.

MATERIALS AND METHODS

Site description

This investigation was conducted at LeDong banana wilt disease experimental site (18° 23′ -18° 52′ N, 108°36′ - 109°05′ E), Chinese Academy of Tropical Agricultural Sciences, Hainan, China. The mean annual temperature is 21.5-28.5°C and the mean annual precipitation is 1600 to 2600 mm with no frost period all year. The annual mean wind velocity is 2.0 to 2.5 m s^{-1}. The test soil is classified as sandy loam with 4.9 g kg^{-1} total organic C, 0.7 g kg^{-1} total N, 0.4 g kg^{-1} total P, 25.1 g kg^{-1} total K and pH 6.0. Banana plants of cvs. Baxijiao (AAA) were sowed in a conventional tillage system. Each banana plant was fertilized by adding 0.5 kg N, 0.3 kg P_2O_5 and 1.5 kg K_2O, respectively. Two sites, the disease area (banana wilt disease soil) and control (healthy banana soil) were arranged with three replicates.

Sampling, extraction and identification of nematodes

The soil samples were collected at depth intervals of 0 to 10, 10 to 20 and 20 to 30 cm below the soil surface on booting stage (March 19, 2010) within the plant rows of banana plants, and 50 cm from the base of the banana plant. Each sample comprised five soil cores (3.0 cm in diameter) and were placed in individual plastic bag and then immediately stored in 4°C condition.

Nematodes were extracted from 100 g soil sample (fresh weight) by a modified cotton-wool filter method (Verschoor and de Goede, 2000). The abundance of nematodes was expressed per 100 g dry weight soil. Nematodes were identified to genus level using an inverted compound microscope. The classification of trophic groups was assigned to: bacterivores (BF), fungivores (FF), plant parasites (PP) and omnivores-predators (OP), based on known feeding habits or stomach and pharyngeal morphology (Yeates et al., 1993).

Soil chemical analysis

Total organic C (TOC) was analyzed by dry combustion, using a Shimadzu TOC 5000 Total C analyzer. Soil pH was determined with a glass electrode in 1 : 2.5 soil : water solution (w/v). Total nitrogen (TN) was determined by semi-microkjeldahl method. Total P (TP) was digested by H_2SO_4-$HClO_4$ and determined by Molybdenum-blue complex method. Total K (TK) was analyzed by Flame photometer (FP 640, Shanghai, China). Alkaline N (AN), available P (AP) and available K (AK) were described by Rayment and Higginson (1992).

Statistical analysis

The following nematode ecological indices were calculated: (1) dominance $\lambda = \sum P_i^2$; (2) diversity $H' = -\sum P_i (\ln P_i)$, where P_i is the proportion of individuals in the ith taxon; (3) maturity index MI (excluding plant parasites), $MI = \sum v(i) \cdot f(i)$, where v(i) is the c-p value of i-taxon, f(i) is the frequency of i-taxon, which measures disturbances for environment; (4) plant parasite index PPI, which was determined in a similar manner for plant parasitic genera (Yeates and Bongers, 1999); (5) Enrichment index (EI) was calculated as $EI = 100\ e / (b + e)$, structure index (SI) was

Table 1. Changes in soil chemical parameters between disease and control area in three levels soil depths.

Region	Soil depth (cm)	Parameter							
		pH	TOC (g/kg)	TN (g/kg)	TP (g/kg)	TK (g/kg)	Alkaline N (mg/kg)	Available P (μg/kg)	Available K (μg/g)
Disease area	0 - 10	5.17 ± 0.03^{a}	4.03 ± 0.46^{a}	0.77 ± 0.15^{a}	0.44 ± 0.06^{a}	22.08 ± 2.03^{a}	31.87 ± 7.84^{a}	68.41 ± 19.09^{a}	48.27 ± 11.74^{a}
	10 - 20	5.05 ± 0.09^{b}	2.72 ± 0.15^{b}	0.61 ± 0.09^{a}	0.35 ± 0.11^{a}	23.31 ± 8.20^{a}	23.20 ± 3.96^{b}	32.85 ± 4.43^{a}	38.39 ± 15.10^{a}
	20 - 30	5.15 ± 0.04^{a}	2.61 ± 0.33^{b}	0.65 ± 0.09^{a}	0.34 ± 0.13^{a}	21.91 ± 2.84^{a}	28.74 ± 8.70^{b}	33.31 ± 2.38^{a}	42.39 ± 1.68^{a}
CK	0 - 10	5.29 ± 0.08^{b}	6.15 ± 0.37^{b}	0.82 ± 0.10^{b}	0.34 ± 0.01^{a}	25.73 ± 2.16^{a}	74.40 ± 11.03^{a}	24.98 ± 3.87^{a}	72.80 ± 13.77^{a}
	10 - 20	5.97 ± 0.12^{ab}	6.45 ± 0.1^{b}	0.76 ± 0.10^{b}	0.33 ± 0.02^{a}	26.63 ± 3.43^{a}	60.69 ± 4.39^{b}	28.08 ± 2.61^{a}	46.25 ± 1.79^{b}
	20 - 30	6.48 ± 0.8^{a}	7.28 ± 0.18^{a}	0.95 ± 0.09^{a}	0.34 ± 0.01^{a}	30.85 ± 2.56^{a}	62.34 ± 1.31^{b}	33.25 ± 2.62^{a}	46.61 ± 9.74^{b}
Effects	Site	<0.01	<0.01	<0.01	<0.01	ns	<0.01	0.018	0.029
	Depth	0.034	0.033	ns	ns	ns	0.012	ns	0.021
	Site × Depth	0.026	<0.01	ns	ns	ns	<0.01	ns	ns

Mean values and standard deviation of three replicates are presented. Significant differences of variable means the two treatments are indicated by different letter behind ($P < 0.05$). Ns: non-significant ($P > 0.05$). TOC, Total organic content; TN, total nitrogen; TP, total phosphorus; TK, total potassium.

calculated as SI = 100 s / (b + s), where s = 1.8 × (Ba_3 + Fu_3 + OP_3) + 3.2 × (Ba_4 + Fu_4 + OP_4) + 5 × (Ba_4 + Fu_5 + OP_5), b = 0.8 × (Ba_2 + Fu_2), e = 3.2 × (Ba_1) + 0.8 × (Fu_2). The numbers from 1 to 5 represented five life-history groups of soil nematodes (c-p 1to5) (Ferris et al., 2001).

Nematode abundances were ln (x+1) transformed prior to statistical analysis and expressed as numbers per 100 g dry soil. Soil chemical properties were analyzed through a two-way ANOVA (site × depth) to determine the between-subject effects. All statistical analyses were performed by SPSS software package. Difference at $P < 0.05$ level was considered as statistically significant.

RESULTS

Soil properties

Soil pH, the contents of TOC, TN, TP and AN were significantly lower ($P < 0.01$) in the disease area than in the control area (Table 1). The content of TOC, AN and AK sharply decreased ($P < 0.05$) with the increase of soil depth in both areas in 0 to 20 cm (Table 1). Significant site effects ($P < 0.01$) were observed in the pH, the contents of TOC, TN, TP and AN, significant depth effects ($P < 0.05$) were observed in the pH, contents of TOC, AN and AK and significant interaction of site and depth effects ($P < 0.01$) were also observed in the contents of TOC and Alkaline N (Table 1).

Total abundance of soil nematodes

26 and 28t nematode genera were identified in the disease and control area, respectively (Table 2). The highest values of nematode genera richness in the disease area (21 genera) and control area (24 genera) were all found at the depth of 10-20 cm. The disease area was dominated by *Acrobeles*, *Acrobeloides*, *Aphelenchus* and *Chiloplacus*, with the highest value of relative abundance 18.7% for *Acrobeles* in 0 to 10 cm, the secondary 16.8% for *Acrobeloides* in 0 to 20 cm, the tertiary 16.1% for *Aphelenchus* in 0 to 10 cm and the 12.4% for *Chiloplacus* in 10 to 20 cm; while control area was dominated by *Pelodera*, *Basiria*, *Protorhabditis* and *Ditylenchus*, with the highest value of relative abundance 18.9% for *Pelodera* in 10 to 20 cm, the secondary 18.7% for *Basiria* in 10 to 20 cm, the tertiary 15.7% for *Protorhabditis* in 0 to 10 cm and the 12.5% for *Ditylenchus* in 0 to 10 cm; *Paratylenchus* was the dominant genus in both areas with the relative abundance 21.5% in 0 to 30 cm.

The abundance of total nematodes decreased sharply with the increase of soil depth in both areas, with the highest value (213 individuals 100 g^{-1} soil) in the control area at 0 to 10 cm, and the lowest value (125 individuals 100 g^{-1} soil) in the disease area at 20 to 30 cm (Figure 1). In the disease area, 37.6% soil nematode was distributed in 0 to 10 cm, 33.3% in 10 to 20 cm and

Table 2. Average percentage dominance values (c-p) for nematode genera in banana wilt disease area and control area (%).

Trophic groups/genus	c-p [b]	Disease area (cm)			CK (cm)		
		0 - 10	10 - 20	20 - 30	0 - 10	10 - 20	20 - 30
Ba[a]		**55.2**	**47.5**	**41.7**	**36.0**	**48.7**	**46.8**
*Pelodera** [c]	1	0.0	0.0	0.0	4.5	18.9	12.1
*Protorhabditis**	1	0.0	0.8	1.2	15.7	6.5	7.7
Panagrolaimus	1	2.7	1.9	1.3	1.1	2.3	2.5
Monhystera	1	1.6	0.6	0.0	1.0	0.9	1.0
Eucephalobus	2	2.2	0.0	0.0	2.3	2.8	6.1
Heterocephalobus	2	0.9	1.9	0.9	1.7	1.4	1.8
*Acrobeles**	2	18.7	2.5	0.0	0.0	0.0	0.0
*Acrobeloides**	2	16.8	16.8	17.2	7.5	7.3	7.6
Cervidellus	2	0.7	0.0	1.0	0.0	0.0	0.0
*Chiloplacus**	2	4.0	12.4	11.4	0.5	0.0	0.5
Plectus	2	3.3	3.3	0.9	0.0	0.9	0.8
Wilsonema	2	1.1	0.0	0.0	0.0	0.0	0.0
Chronogaster	2	0.0	0.0	0.9	0.0	1.1	0.5
Prismatolaimus	3	2.6	6.7	5.7	1.7	6.0	5.7
Alaimus	4	0.6	0.6	1.2	0.0	0.6	0.5
Fu		**18.4**	**22.4**	**19.9**	**17.0**	**6.8**	**12.5**
*Ditylenchus**	2	1.6	7.2	8.6	12.5	3.4	3.3
*Aphelenchus**	2	16.1	14.6	9.8	4.0	1.7	7.9
Aphelenchoides	2	0.7	0.6	1.5	0.0	1.1	0.0
Tylencholaimus	4	0.0	0.0	0.0	0.5	0.6	1.3
PP		**23.1**	**27.9**	**36.8**	**45.0**	**42.2**	**40.2**
*Basiria**	2	1.8	5.3	7.7	12.1	18.7	14.0
Tylenchus	2	0.0	0.0	0.0	0.8	1.7	1.0
Filenchus	2	0.0	1.6	0.9	6.1	2.8	2.8
*Paratylenchus**	2	21.3	17.6	25.7	18.5	15.3	15.5
Helicotylenchus	3	0.0	0.0	0.0	6.5	3.1	6.2
Rotylenchus	3	0.0	0.8	1.9	0.0	0.6	0.5
Hirschmanniella	3	0.0	0.6	0.0	0.7	0.0	0.0
Longidorella	4	0.0	2.0	0.6	0.3	0.0	0.0
OP		**3.3**	**2.2**	**1.6**	**2.0**	**2.3**	**0.5**
Thonus	4	1.5	1.1	0.9	0.0	0.6	0.5
Dorydorella	4	0.5	0.0	0.0	0.5	0.9	0.0
Microdorylaimus	4	1.3	1.1	0.7	0.7	0.9	0.0
Prodorylaimus	5	0.0	0.0	0.0	0.8	0.0	0.0

[a] Ba = bacterivores, Fu = fungivores, PP = plant parasites, OP = omnivores-predators; [b] numbers following the functional groups indicate the c-p values (Bongers and Bongers, 1998; Ferris et al., 2001); [c] * dominant genera (>10%)

29.1% in 20 to 30 cm; in the control area, 36.9% soil nematode distributed in 0 to 10 cm, 33.2% in 10 to 20 cm and 29.9% in 20 to 30 cm. The abundance of total nematodes was significantly lower (P <0.01) in the disease area than in the control area (Figure 1). Significant site and depth effects were observed in the

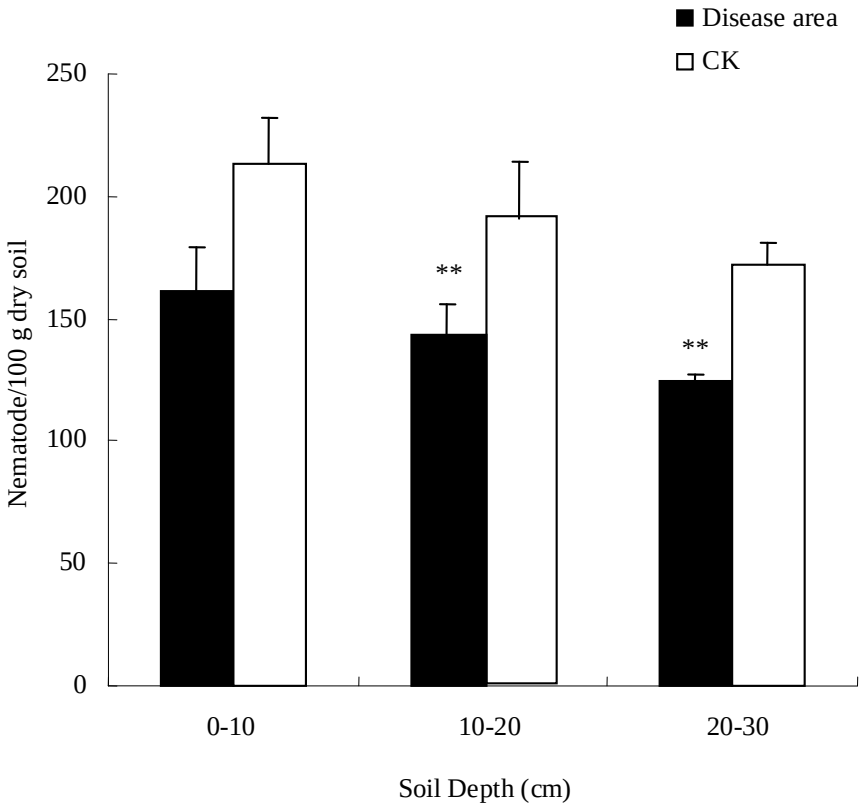

Figure 1. Changes in abundance (individuals per 100 g dry soil) of total nematodes between banana wilt disease area and control area in the three soil level depths (Significant levels: **, P <0.01; *, P <0.05).

abundance of total nematodes.

Nematodes trophic groups

The abundance of bacterivore decreased sharply (P<0.01) with the increase of soil depth in the disease area (Figure 2). The abundance of bacterivore was significantly lower (P <0.01) in the disease area than in the control area in 10 to 30 cm (Figure 2). The highest value of 93 individuals 100 g^{-1} soil was observed in the control area in 10 to 20 cm and the lowest value of 52 individuals 100 g^{-1} soil was observed in the disease area in 20 to 30 cm (Figure 2). Significant depth effects were observed in the abundance of bacterivore in the disease area, but not observed in the control area.

The abundance of fungivores was significantly higher (P < 0.01) in the disease area than in the control area in 10 to 20 cm (Figure 2). The highest value of 36 individuals 100 g^{-1} soil and the lowest value of 13 individuals 100 g^{-1} soil were both observed in the control area in 0 to 10 and 10 to20 cm (Figure 2). Significant site effects were observed in the abundance of fungivores in the disease area and control area.

The abundance of plant parasites increased sharply (P<0.01) with the increase of soil depth in the disease area and decreased (P < 0.05) with the increase of soil depth in the control area (Figure 2). The abundance of plant parasites was significantly lower (P <0.01) in the disease area than in the control area (Figure 2). The highest value of 96 individuals 100 g^{-1} soil was observed in the control area in 0 to 10 cm and the lowest value of 36 individuals 100 g^{-1} soil was observed in the disease area in 0 to 10 cm (Figure 2). Significant site and depth effects were observed in the abundance of plant parasites in the disease area and control area. Also, the abundance of omnivores-predators was significantly lower (P <0.01) in the disease area than in the control area in 10 to 20 cm. The highest value of 6 individuals 100 g^{-1} soil was observed in the disease area in 0 to 10 cm and the lowest value of 2 individuals 100 g^{-1} soil was observed in the control area in 20 to 30 cm (Figure 2). Significant site effects were observed in the abundance of omnivores-predators in both areas.

Nematode ecological indices

The values of H', MI, PPI, EI and SI were significantly lower (P <0.01) in the disease area than in the control

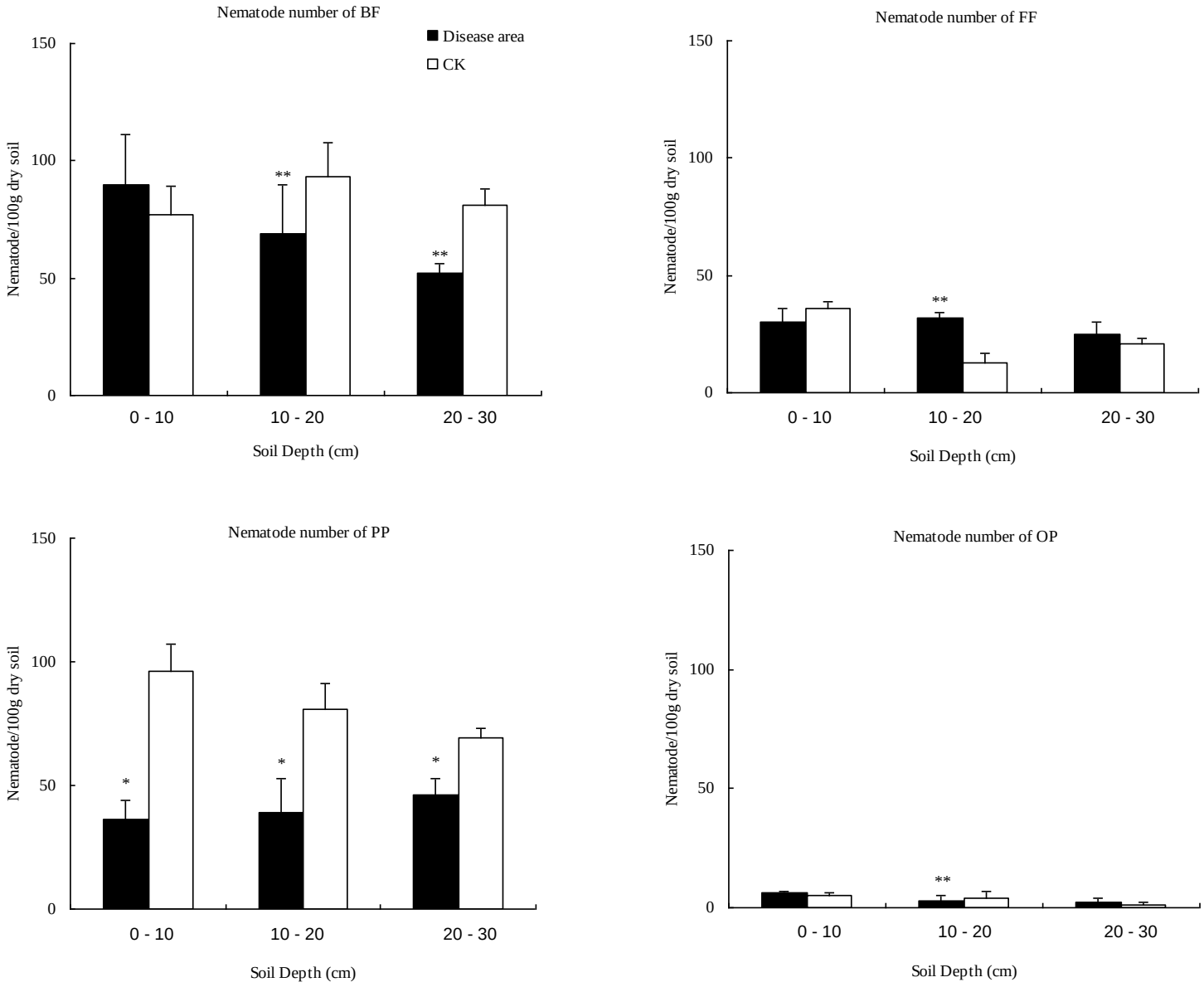

Figure 2. Abundance of four trophic groups of soil nematodes between banana wilt disease area and control area in the three soil level depths (Significant levels: **, P <0.01; *, P <0.05).

area, while those of λ exhibited quite a reverse condition (Table 3). The highest values of H', MI, PPI, EI and SI were observed in the control area in 10 to 20 and 20 to 30 cm, while the lowest values of H', MI, PPI, EI and SI were observed in the disease area in 0 to 10 and 10 to 20 cm (Table 3). The highest and lowest values of λ were observed in the control area and disease area in 0 to 10 and 20 to 30 cm (Table 3). The values of SI increased sharply (P <0.01) with the increase of soil depth in both areas in 0 to 20 cm (Table 3).

More also, significant site effects (P < 0.01) were observed in the values of λ, H', MI, PPI, SI and EI, significant depth effects (P < 0.01) were observed in the values of SI, significant interaction of site and depth effects (P < 0.01) were observed in the values of MI (Table 3) and significant correlations were observed between the EI and the contents of TOC (r = 0.922, P < 0.01) and TN (r = 0.586, P < 0.05).

DISCUSSION

Comparison of soil chemical property between banana wilt disease soil and healthy soil

Decomposition of organic matter, nutrient cycling and control of infectious diseases are some key roles of soil beneficial microbes in soil ecosystems (Seneviratne,

Table 3. Changes in the values of nematode ecological indices between banana wilt disease area and control area in the three soil level depths.

Region	Soil depth (cm)	Indices					
		λ	H'	MI	PPI	EI	SI
Disease area	0 - 10	0.16 ± 0.03[a]	2.23 ± 0.12[a]	1.74 ± 0.06[a]	2.00 ± 0.02[b]	34.94 ± 0.51[a]	25.30 ± 2.70[b]
	10 - 20	0.12 ± 0.01[a]	2.37 ± 0.10[a]	1.73 ± 0.11[a]	2.09 ± 0.15[a]	37.50 ± 0.92[a]	29.73 ± 7.04[a]
	20 - 30	0.15 ± 0.01[a]	2.24 ± 0.11[a]	1.78 ± 0.09[a]	2.08 ± 0.06[a]	36.65 ± 4.98[a]	30.17 ± 14.36[a]
CK	0 - 10	0.11 ± 0.02[ab]	2.44 ± 0.02[a]	2.09 ± 0.03[a]	2.18 ± 0.03[b]	78.88 ± 1.31[b]	35.48 ± 12.54[b]
	10 - 20	0.12 ± 0.01[a]	2.49 ± 0.13[a]	2.12 ± 0.04[a]	2.22 ± 0.03[a]	86.54 ± 1.20[a]	58.14 ± 9.67[a]
	20 - 30	0.10 ± 0.01[b]	2.55 ± 0.11[a]	2.14 ± 0.10[a]	2.17 ± 0.05[b]	78.89 ± 1.29[b]	43.03 ± 11.94[a]
Effects	Site	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Depth	ns	ns	ns	ns	ns	<0.01
	Site × Depth	ns	ns	<0.01	ns	ns	ns

Mean values and standard deviation of three replicates are presented. Significant differences of variable means the two treatments are indicated by different letter behind ($P < 0.05$). Ns: Non-significant ($P > 0.05$). λ, Dominance; H', values of diversity; MI, maturity index; PPI, plant parasite index; EI, enrichment index; SI, structure index.

2009). In our study, soil pH, the contents of TOC, TN, TP and AN were significantly lower in the disease area than in the control area. Penga et al. (1999) reported that the increased abundance of FOC strongly inhibited the abundance of soil beneficial microbes which in turn decreased soil pH, the contents of TOC, TN and TP indirectly. Previous studies indicated that banana wilt disease caused by inadequate soil management seriously decreased soil pH, total organic C, alkaline N and available K, Ca, Mg, B and Zn, and increased soil compaction (Dominguez et al., 2003; Nasir et al.,2003). Sharma et al. (2010) observed that the optimum living environments for Fusarium oxysporum correlated with serious disturbance conditions such as low pH, low organic matters and deficient nutrients.

Comparison of soil nematode communities between banana wilt disease soil and healthy soil

The mean abundance of bacterivores was 17.5% lower in the disease area than in the control area in 0 to 20 cm, which was in agreement with those in a tomato wilt disease field (Nasir et al., 2003). Decreased abundance of bacterivores was associated with increased abundance of FOC which in turn strongly inhibited the abundance of soil beneficial bacteria in disease areas (Neher, 2005; Quénéhervé, 2008). Nieminen (2009) observed that soil beneficial bacteria provided available food resources for nematodes of Cephalobidae and Rhabditidae reproduced themselves. However, the mean abundance of fungivores was 40.2% higher in the disease area than in the control area. It was higher than the results of McKenzie and Dixon (2006) who suggested that FOC created a food base for fungivores, and that the increased abundance of FOC strongly increased the abundance of fungivores. Yeoung and Guy, (2008) reported that some kinds of fungivores such as *Aphelenchus avenae* and *Aphelenchoides bicaudatus* showed favor to *Fusarium oxysporum* as consumers of soil fungi.

In addition, the mean abundance of plant parasites was 59.6% lower in the disease area than in the control area. This was a little higher than the results of Shreenivasa (2005) who observed that banana wilt disease damaged plant root system and decreased the total weight of banana roots by 30%, which in turn decreased the food resources available for plant-parasitic nematodes. And the mean abundance of omnivores-predators was 4.5% lower in the disease area than in the control area in 10 to 20 cm. Omnivores-carnivores representing higher-order trophic groups were sensitive to a variety of disturbances such as banana wilt disease (Ferris and Bongers, 2006). Wang et al. (2006) reported that plant parasites were the main food resources of omnivores-carnivores under low soil nutrient condition, and the decreased abundance of omnivores-predators also attributed to the decreased abundance of prey.

Different trophic groups and genera had different preference to soil profiles. Most bacterivores were restricted to a depth of 0 to10 cm in the disease area and control area because there was much greater soil microbial biomass in the surface soil than in the subsurface soil and these were easy for bacterivores to attain the microbial resource as food (Cao et al., 2008). The high density of plant parasites therefore appeared in

the profile of 10 to 30 cm in the disease area and control area because plant roots were mainly distributed in this region and it was relatively easy for plant parasites to get food resources (Zhi et al., 2008).

Comparison of soil nematode ecological indicators between banana wilt disease soil and healthy soil

Diversity index (H') gives more weight to rare species with higher values showing a greater diversity, while dominance index (λ) gives more weight to common species (Ferris and Bongers, 2006). The average value of H' was 8.5% lower in the disease area than in the control area, while that of λ was 23.3% higher in the disease area than in the control area, which was in agreement with the results of Pattison et al. (2008) in north Queensland. These apparent differences were attributed to a decline in abundance of omnivores-predators and enhancement in abundance of fungivores in the disease area (Neher et al., 2005). Furthermore, *Acrobeles*, *Acrobeloides*, *Chiloplacus* and *Aphelenchus* comprised 64.4% of the abundance of total nematodes in the disease area, which contributed to a significantly lower diversity and higher dominance of nematodes in the disease area relative to the control area (Kimpinski and Sturz, 2003).

The average values of MI and PPI were 17.5% and 2.3% lower in the disease area than in the control area. The low values of MI and PPI in the disease area were attributed to a more unstable environmental condition and more disturbed soil food web compared to the control area (Yeates, 2003). The MI values of smaller than two (MI<2) in the disease area were attributed to high abundance of tolerant species (*r*-strategists) such as fungivores and low abundance of sensitive species (*K*-strategists) such as omnivores-carnivores, and a decrease in plant root production decreased the abundance of plant parasites contributed to lower values of PPI in the disease area compared to the control area (Rossouw, 2008).

The structure index (SI) is primarily determined by omnivorous and predatory nematode populations, which are sensitive to disturbance and need much more time to establish compared to more rapidly growing bacterivores and fungivores (Ferris et al., 2001). The average value of SI was 37.6% lower in the disease area than in the control area. The lower values of SI in the disease area were due to lower abundances of carnivores-omnivores. The reduction or elimination of the carnivore-omnivores indicated a reduction in the complexity of the soil food web and a shortening of food chains in banana diseased soils (Ferris et al., 2010). The values of SI increased with the increase of soil depth in the disease area in 0 to 30 cm, thus suggesting that the effects of disturbance caused by FOC on the soil nematode community were more pronounced at the 0 to 10 cm than the 10 to 30 cm.

The enrichment index (EI) reflects the availability of resources to the soil food web and the response of primary decomposers to the resources (Ferris et al., 2001). The average value of EI was 55.3% lower in the disease area than in the control area, which indicated that the increasing abundance of FOC decreased food resources for the soil food web by inhibiting the growth of soil bacterial and bacterivores nematodes. Okada and Harada (2007) reported that low nutrient inputs and less organic matter turnover decreased the abundance of bacterivores, those were capable of responding quickly to the increased food supply and therefore decreased the values of EI.

Conclusion

Banana wilt disease caused by *F. oxysporum* f.sp. *cubense* (FOC) changed soil properties and nematode community composition such as decreasing soil pH, the content of TOC and TN, the abundance of bacterivore, plant parasites and omnivores-predators and the values of H', MI, PPI, SI and EI in comparison with the control area. The results obtained in this study suggested that the increased abundance of FOC in banana wilt disease area did decrease certain soil nutrient availability and disturbed soil food web compared with the control area. Nematode community analysis is therefore a powerful tool that can be used together with more conventional soil physical and chemical tests to develop a deeper understanding of how banana wilt disease impacts on the health of soil ecosystem.

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REFERENCES

Berkelmans R, Ferris H, Tenuta M, van Bruggen AHC (2003). Effects of long-term crop management on nematode trophic levels other than plant feeders disappear after 1 year of disruptive soil management. Appl. Soil Ecol. 23: 223-235.

Bhuvanendra KH, Udaya SAC, Chandra NS, Ramachandra KK, Shetty HS, Prakash HS (2010). Biochemical characterization of *Fusarium oxysporum* f. sp. *cubense* isolates from India. Afr. J. Biotechnol. 9(4): 523-530.

Cao CY, Jiang DM, Teng XH, Jiang Y, Liang WJ, Cui ZB (2008). Soil chemical and microbiological properties along a chronosequence of *Caragana microphylla* Lam. plantations in the Horqin sandy land of Northeast China. Appl. Soil Ecol. 40: 78-85.

De Waele D, Stoffelen R, Kestemont J (2006). Effect of associated plant

species on banana nematodes. Info*Musa*, 15: 2-6.
Dominguez J, Negrin MA, Rodriguez CM (2003). Evaluating soil sodium indices in soils of volcanic nature conducive or suppressive to fusarium wilt of banana. Soil Biol. Biochem. 35: 565-575.
Dominguez J, Negrin MA, Rodriguez CM (2008). Soil potassium indices and clay-sized particles affecting banana wilt expression caused by soil fungus in banana plantation development on transported volcanic soils. Commun. Soil Sci. Plan. 39: 397-412.
Duyck PF, Pavoine S, Tixier P (2009). Host range as an axis of niche partitioning in the plant-feeding nematode community of banana agroecosystems. Soil Biol. Biochem. 41: 1139-1145.
Ferris H (2010). Form and function: metabolic footprints of nematodes in the soil food web. Euro. J. Soil Boil. 46: 97-104.
Ferris H, Bongers T (2006). Nematode indicators of organic enrichment. J. Nematol. 38: 3-12.
Ferris H, Bongers T, de Goede RGM (2001). A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. Appl. Soil Ecol. 18: 13-29.
Goodsell PJ, Underwood AJ, Chapman MG. (2009). Evidence necessary for taxa to be reliable indicators of environmental conditions or impacts. Mar. Pollut. Bull. 58: 323-331.
Goswami BK, Pandey RK, Goswami J, Tewari DD (2007). Management of disease complex caused by root knot nematode and root wilt fungus on pigeonpea through soil organically enriched with Vesicular Arbuscular Mycorrhiza, karanj (*Pongamia pinnata*) oilseed cake and farmyard manure. J. Environ. Sci. Health B. 42: 899-904.
Goswami J, Tiwari D (2007). Management of *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *lycopersici* Disease Complex on Tomato by *Trichoderma harzianum, Tinopsora longifolia* and *Glomus fasciculatum.* Pestic. Res. J. 19(1): 51-55.
Haseeb A, Sharma A, Abuzar S, Kumar V (2006). Evalution of resistance in different cultivars of chickpea against *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *ciceri* under field conditions. Indian Phytopath. 59(2): 234-236.
Haseeb A, Sharma A, Shukla PK (2005).Studies on the management of root-knot nematode, *Meloidogyne incognita*-wilt fungus, *Fusarium oxysporum* disease complex of green gram, *Vigna radiat*a cv ML-1108. J. Zhejiang Univ. 6B(8): 736-742.
Hohberg K (2003). Soil nematode fauna of afforested mine sites: genera distribution, trophic structure and functional guilds. Appl. Soil Ecol. 22: 113-126.
Kimpinski J, Sturz AV (2003). Managing crop root zone ecosystems for prevention of harmful and encouragement of beneficial nematodes. Soil Tillage Res. 72(2): 213-221.
McKenzie NJ, Dixon J (2006). Monitoring soil condition across Australia: Recommendations from the Expert Panels. National Land and Water Resource Audit, Australian Government, Canberra, Australia.
Nasir N, Pittaway PA, Pegg K (2003). Effects of organic amendments and solarisation on Fusarium wilt in susceptible banana plantlets, transplanted into naturally infested soil. Aust. J. Soil. Res. 54: 251-257.
Neher DA (2001). Role of nematodes in soil health and their use as indicators. J. Nematol. 33: 161- 168.
Neher DA, Wu J, Barbercheck ME, Anas O (2005). Ecosystem type affects interpretation of soil nematode community measures. Appl. Soil Ecol. 30: 47-64.
Nieminen JK (2009). Modelling the interactions of soil microbes and nematodes. Nematology, 4(11): 619-629.
Pattison AB, Moody PW, Badcock KA, Smith LJ, Armour JA, Rasiah V, Cobon JA, Gulino LM, Mayer R (2008). Development of key soil health indicators for the Australian banana industry. Appl. Soil Ecol. 40: 155-164.
Penga HX, Sivasithamparama K, Turner DW (1999). Chlamydospore germination and *Fusarium wilt* of banana plantlets in suppressive and conducive soils are affected by physical and chemical factors. Soil Biol. Biochem. 31: 1363-1374.
Poornima K, Angappan K, Kannan R, Kumar N, Kavino M, Balamohan TN (2007). Interactions of nematode with the fungal Panama wilt disease of banana and its management. Nematol. Medit. 35: 35-39.
Quénéhervé P (2008). Integrated management of banana nematodes. In: Ciancio A, Mukerji KG. (Eds.), Integrated Management of Fruit Crops Nematodes. Springer, The Netherlands, pp. 1-54.
Rayment GE, Higginson FR (1992). Australian Laboratory Hand book of Soil and Water Chemical Methods. Inkata Press, Sydney, Australia. pp. 25-133.
Rossouw J, van Rensburg L, Claassens S, van Rensburg PJJ (2008). Nematodes as indicators of ecosystem development during platinum mine tailings reclamation. Environmentalist, 28: 99-107.
Schloter M, Dilly O, Munch JC (2003). Indicators for evaluating soil quality. Agric. Ecosyst. Environ. 98: 255-262.
Seneviratne G (2009). Collapse of beneficial microbial communities and deterioration of soil health: a cause for reduced crop productivity. Curr. Sci. India, 5(96): 633.
Sharma BR, Dutta S, Roy S, Debnath A, De Roy M (2010). The effect of soil physico-chemical properties on rhizome rot and wilt disease complex incidence of ginger under hill agro-climatic region of west Bengal. Plant Pathol. J. 2(26): 198-202.
Shreenivasa KR, Krishnappa K, Reddy BMR, Ravichandra NG, Karuna K, Kantharaju V (2005). Integrated Management of Nematode complex on banana. Indian J. Nematol. 1(36): 37-40.
Stirling GR, Stirling AM, Seymour NP, Bell MJ (2004). Use of free-living nematodes in soil food-web diagnostics: An example from the vertosols of the northern grain belt. *Proceedings of the Third Australasian Soilborne Diseases Symposium*, Rowland Flat, South Australia. South Aust. Res. Dev. Institute, pp. 3-4.
Verschoor BC, de Goede RGM (2000). The nematode extraction efficiency of the Oostenbrink elutriator-cottonwool filter method with special reference to nematode body size and life strategy. Nematology, 2: 325-342.
Wang KH, McSorley R, Marshall A, Gallahe RN (2006).Influence of organic Crotalaria juncea hay and ammonium nitrate fertilizers on soil nematode communities. Appl. Soil Ecol. 31: 186-198.
Wu HS, Yang XN, Fan JQ, Miao WG, Ling N, Xu YC, Huang QW, Shen Q (2009). Suppression of *Fusarium wilt* of watermelon by a bio-organic fertilizer containing combinations of antagonistic microorganisms. Bio. Control, 54: 287-300
Yeates GW (2003).Nematodes as soil indicators: functional and biodiversity aspects. Biol. Fertil. Soils, 37: 199-210.
Yeates GW, Bongers T (1999). Nematode diversity in agroecosystem. Agric. Ecosyst. Environ. 74: 113-135.
Yeates GW, Bongers T, de Goede RGM, Freckman DW, Georgieva SS (1993). Feeding habits in soil nematode families and genera - an outline for soil ecologists. J. Nematol. 25: 315-331.
Yeoung-Seuk B, Guy RK (2008). Influence of a Fungus-Feeding Nematode on Growth and Biocontrol Efficacy of *Trichoderma harzianum*. Phytopathology, 3(91): 301-306.
Yucel S, Ozarslandan A, Colak A (2009). Methyl bromide alternatives for controlling fusarium wilt and root knot nematodes in tomatoes in Turkey. Acta. Hortic. 808: 381-385.
Zhi DJ, Li HY, Nan WB (2008). Nematode communities in the artificially vegetated belt with or without irrigation in the Tengger Desert, China. Euro. J. Soil Boil. 44: 238-246.