Effect of soil management on biodiversity of nematode communities as a biological indicator of soil quality in oasis agro-ecosystem of Kebili

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ABSTRACT

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Nematode communities were monitored in 26 oases in Kebili under various agricultural systems. Differences between studied oases consisted in tillage frequency, soil amendment type (manure or manure+ mineral fertilizers), cover crops and field age. In addition, this study evaluated the importance of the C-P (Colonizer-Persistent) triangle and the faunal profile (representation of enrichment index vs. structure index) as a biological indicator and monitoring tools in support of soil quality assessment. The results showed that nematode communities were composed by 10 bacterial feeders (Ba), 3 fungal feeders (Fu), 12 plant parasites (PP), 4 omnivores (O), 1 predator (P) with the dominance of (Ba) and (PP) in all surveyed oases. The nematode communities differed slightly depending on oases age. Bacterial feeders and *Discolaimium* genus were found in both young and old ones. *Plectus* genus (Ba) was found only in young oases while *Xiphinema*, *Criconema* and *Trichodorus* genera (PP) were absent in these oases. Few nematode taxa were affected by soil amendment type and cover crops including some bacterial and fungal feeders. The highest taxa richness was recorded in bare soils and in field with tillage frequency of 2 or 3 years. The lower MI (Maturity index) value was recorded in old oases. Most of studied oases were characterized either by a high soil disturbance level with a high abundance of cp-1 group (Bacterivore nematodes with c-p value =1)as an indicator of a disturbed food web or by a stressed soil with high abundance of cp-2 group (Bacterivore and fungivore nematodes with c-p value = 2) as an indicator of degraded food web. Only few sites showed a maturing and structured food webs with respectively low to moderate soil disturbance level and undisturbed soil. This study highlighted also that some nematode genera may potentially serve as differential bio-indicators of soil disturbance.

Key words: Agricultural system, biodiversity, date palm, ecological indices, nematode community, oases, soil

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Nematodes are multicellular animals found in all soil and aquatic systems in any environment that provides a source of organic carbon, under all climatic conditions, and in all habitats (Bongers and Ferris 1999). They are playing major roles in component process of ecosystem services. Their populations respond rapidly to disturbance and enrichment and individuals do not rapidly migrate from stressful conditions. In soil and aquatic food webs, nematodes are involved in the transformation of organic matter into mineral and organic nutrients which are available to plants and enhance plant growth and crop productivity (Ferris et al. 2004).

Nematodes are abundant, ubiquitous and diverse, participate in several soil food web links and are sensitive to agricultural disturbance (Yeates 2003). Both in natural areas and under experimental conditions, nematode assemblages are used to assess the effects of pollution (Korthlas et al 1996), and as indicators of soil enrichment and disturbance (Berkelmans et al. 2003; Bongers 1990; Ferris et al. 2001). The composition and structure of terrestrial nematode communities vary among ecosystems because of contrasting plant composition and phenology, soil properties and microclimates (Neher 2010).

In agricultural fields, nematode abundance and diversity are used to infer soil process rates (Ettema et al 1998), soil functions and effects of disturbance on soil fauna (Wardle et al 1995). According to Neher (2001), composition and abundance of the nematode fauna have been used as soil health indicators in many different environments, and it was also reported by Ettema et al. (1998), that the tight relationships between soil characteristics and abundance of nematode in different functional guilds have been used to develop soil assessment criteria. Among soil organisms, nematodes possess several attributes that make them good indicators.

In comparison to many natural ecosystems, the agro-ecosystems receive numerous human actions that may cause serious fauna and flora disruption. Practices such as soil preparation and over use of fertilizers and pesticides can result in a decrease in soil microbial diversity (Timper 2014). In oases, cropping system is conducted under 3 stages of cultures where various fruit trees, vegetables and forage species are cultivated usually in association with date palm. The management of such agro-ecosystem is characterized by frequent soil tillage, a high organic matter (manure) input and the use of some fertilizers for the growth of date palm associated forage cultures. Thus, the special microclimate, the different agricultural techniques and diversification of host plant species incite the multiplication of many groups of soil nematode populations. Since nematodes are considered as organisms with an appropriate bio-indication potential and relatively good traceable reactions to different changes in the environment Neher (2001) and several researchers described bio-indication of different impacts by nematodes (Pen-Mouratov et al. 2010; Sanchez-Moreno and Navas 2007), we were interested to study the relationship between nematode community structure and different agricultural practices through several ecological indices relative to soil nematode assemblages in some oases of southern Tunisia.

MATERIALS AND METHODS

Soil sampling.

During October 2015, among 13 localities in Kebili (Fig.1), 2 oases of 1 ha of surface (Old and New in the context of age) were randomly chosen from each locality, and 6 individual date palms were sampled from each oasis to have 156 soil samples in total. The sampling from date palm rhizosphere was carried out with a hand auger (5 cm inside diameter) at 60 cm from the palm trunk and at 50 cm of depth from the top layer of bulk soil after removing surface residues. Each sample was then placed in a plastic bag, labeled and stored in a cold room at 4 °C until processed.

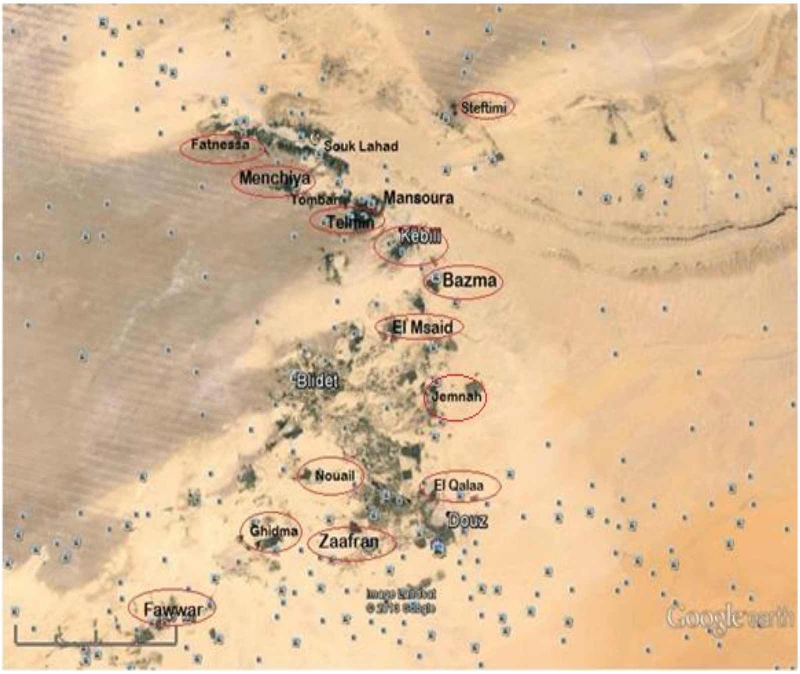

Fig. 1. Geographical localization of the study sites in Kebili, Southern Tunisia

Nematode community analysis.

Soil nematodes were extracted from fresh soil by sieving and Baermann funnel method (Barker et al. 1985). Nematode abundance (N) was expressed as the total individual number per 100 g of dry soil. Collected nematodes from each sample were counted at stereomicroscope (50× magnification). Nematodes were mounted on temporary slides and identified at higher magnification (microscope) to genus or family level using key of Bongers (1988). Nematode taxa were classified into five main trophic groups: bacterial-feeders (Ba), fungal-feeders (Fu), plant parasites/herbivores (PP), omnivores (O), and predators (P) (Yeates et al. 1993).

In addition, they were classified along the colonizer-persiter (cp) scale according to Bongers (1990). The cp scale comprises five groups of nematode families, namely microbial feeders with short life cycles and high reproduction rates (cp 1 and cp 2) and predators and omnivores with long life cycles, low reproduction rates (cp 3) and those which are very sensitive to environmental perturbations (cp 4 and cp 5). Taxa richness (S) was expressed as the average number of taxa in each sample.

Ecological indices.

Several ecological indices were calculated including the Maturity Index (MI) and the Plant-Parasitic Index (PPI) (Bongers 1990) as a weighted means of the relative contribution of each cp group to the assemblage of free-living nematodes (MI) and of plant parasitic nematodes (PPI), respectively.

Additionally, four soil food web indices were calculated: (i) The Structure Index (SI), a weighted measure of the proportion of sensitive predator and omnivore nematodes, which is a sensitive indicator of soil food web complexity; (ii) The Channel Index (CI), based on the ratio of fungivore to bacterivore nematodes, which is an indicator of the prevalence of organic matter decomposition mediated by fungi; (iii) The Basal Index (BI), based on the abundance of general opportunistic nematodes, which is an indicator of basal, perturbed soil food web condition; and (iv) the Enrichment Index (EI), based on the abundance of enrichment opportunistic nematodes, which is an indicator of rapid, bacterial mediated organic matter decomposition. A cp triangle and a graphical representation of the SI vs. the EI allows for the diagnosis of the soil food web as disturbed, maturing, structured, or degraded (Ferris et al. 2001).

Indix calculation, the cp triangle and the faunal profile were realized using the NINJA internet tool (https://sieriebriennikov.shinyapps.io/ninja/) (Sieriebriennikov et al. 2014).

Data analyses.

Principal component analysis PCA was performed by STATISTICA software package (StatSoft 1996).

RESULTS

Nematode community composition.

Thirty nematode taxa (10 bacterivores, 3 fungivores, 12 Plant parasites, 4 omnivores, 1 predator) were identified in the study fields. Per trophic group, the most abundant nematode taxa were Rhabditidae, *Acrobeloides* and *Panagrolaimus* in bacterial feeder group (Ba), *Aphelenchus* and *Aphelenchoides* in fungal feeder group (Fu), Tylenchidae, *Pratylenchus*, *Meloidogyne,* and *Tylenchorhynchus* in plant parasitic nematode group (PP), Quedsinematidae and Aporcelaimidae in omnivore nematode group (O) and *Discolaimium* in predator nematode group (P) (Table 1). Nematode populations identified from studied soils were dominated by bacterial feeder group and plant parasitic group. Nematode abundance (N) was about 497 (±444) individuals/100g of dry soil with a mean of 13 (±2) taxa/sample. All bacterial feeder (Ba) taxa were found in both old and young oases except *Plectus* which is only identified in some young oases (Table 1).

For fungal feeders, all taxa were identified in both old and young oases. Some plant parasitic nematodes like *Xiphinema*, *Criconema* and *Trichodorus* were absent in young oases, while *Helicotylenchus* was absent from old oases. From omnivore group, only Aporcelaimidae and Quedsinematidae families were identified in old oases while other omnivore taxa like *Mesodorylaimus* and *Eudorylaimus* were found also in young oases (Table1). *Discolaimium*, the only representing genus for predator group in this study was identified in both old and young oases (Table 1).

Effects of agricultural practices on nematode diversity.

Table 2 shows total taxa richness in fields with different managements. Sampled bare soils showed the higher S value with 28 taxa in comparison to only 23 taxa present in cover-cropped soils. In conventional system (manure + mineral fertilizers) taxa richness was higher (27 taxa) than in organic system (manure) (25 taxa).

Plectus, *Xiphinema*, *Mesodorylaimus* and *Discolaimium* were absent from soils where only manure is used. *Pratylenchoides*, *Criconema* and *Eudorylaimus* were not identified in oases where both manure and mineral fertilisers are incorporated to the soil. In bare studied soils, only *Trichodorus* and *Eudorylaimus* were not found, while other taxa like *Telotylenchus*, *Heterodera*, *Xiphinema*, *Criconema*, *Mesodorylaimus* and *Discolaimium* were absent in cover-cropped (alfalfa or barley) soils.

The less taxa richness S values 17 and 20 were relative to soils tilled each year and in recently tilled soils. *Diploscapter, Plectus, Wilsonema, Prismatolaimus, Rhabdolaimus, Criconema, Trichodorus, Mesodorylaimus, Eudorylaimus* and *Discolaimium* were all absent from fields tilled each year. The highest taxa richness values 27 and 28 were relative to oases where tillage frequency is about 2 or 3 years and in soils tilled 1 year ago before sampling date where only *Trichodorus* and *Xiphinema* were absent (Table 3).

Food web indices in relation with soil management.

It is also obvious that the presence of cover crops associated with date palm trees have decreased nematode abundance in studied fields. Data from Table 4 shows that N was higher (522 ± 500 individuals/100g of dry soil) in bare soils than in cultivated soils (414 ± 110 individuals/100g of dry soil).

Soil tillage has also negatively affected nematode abundance (N) in recently tilled soils and in soils usually tilled each year where this index has the lower values with respectively only 315 and 337 individuals/100g of dry soil. However, in oases where soil is tilled usually each 2 years and only manure is used, nematode abundance showed the highest levels, respectively 567 and 602 individuals/100 g of dry soil. Additionally, in old oases and in oases where soil is tilled just one year before sampling date, nematode abundance showed also higher values, 553 and 534 respectively (Table 4).

The lowest MI value (1.79) was recorded in old oases; this is an indication of the high soil disturbance level. Higher MI values of 2 and 2.09 were registered respectively in young oases and in fields with cover crops in association with date palm. In soils tilled each year or 2 years and in soils tilled just 1 year before sampling date, this index showed also high values respectively 1.97, 1.93 and 1.94.

Table 1. Distribution and abundance of different nematode taxa identified from prospected oases

Taxa or Family	Feeding type	cp value	N	SD	Old	Young
Rhabditidae	Ba	1	88.13	±219.37	+	+
Panagrolaimus	Ba	1	32.82	±35.01	+	+
Diploscapter	Ba	2	5.21	±19.31	+	+
Acrobels	Ba	2	22.78	±25.98	+	+
Acrobeloides	Ba	2	68.15	±46.35	+	+
Cervidellus	Ba	2	13.79	±33.38	+	+
Plectus	Ba	2	0.2	±0.74	-	+
Wilsonema	Ba	2	1.09	±3.055	+	+
Prismatolaimus	Ba	3	4.06	±11.42	+	+
Rhabdolaimus	Ba	3	2.85	±5.52	+	+
Aphelenchus	Fu	2	55.61	±91.97	+	+
Aphelenchoides	Fu	2	21.58	±30.77	+	+
Tylencholaimus	Fu	4	3.25	±12.30	+	+
Pratylenchus	PP	3	74.64	±71.47	+	+
Pratylenchoides	PP	3	0.55	±1.58	+	+
Tylenchidae	PP	2	53.95	±68.19	+	+
Tylenchorhynchus	PP	3	11.75	±17.26	+	+
Telotylenchus	PP	2	1.52	±3.49	+	+
Rotylenchus	PP	3	6.19	±12.40	+	+
Helicotylenchus	PP	3	0.28	±1.21	-	+
Heterodera	PP	3	0.34	±1.098	+	+
Meloidogyne	PP	3	16.44	±30.28	+	+
Xiphinema	PP	5	0.074	±0.36	+	-
Criconema	PP	3	0.2	±0.58	+	-
Trichodorus	PP	4	0.053	±0.26	+	-
Quedsinematidae	O	4	4.27	±6.30	+	+
Aporcelaimidae	O	5	4.72	±5.49	+	+
Mesodorylaimus	O	4	0.41	±1.85	-	+
Eudorylaimus	O	4	0.06	±0.28	-	+
Discolaimium	P	5	0.45	±1.46	+	+
					S = 26	**S = 27**

Presence or absence of each taxa are indicated by + or -; Ba: bacterial feeder group; Fu: fungal feeder group; PP: plant parasitic nematode group; O: omnivore nematode group; P: predator nematode group; S: taxa richness; N: nematodes/100g dry soil; Old: more than 50 years; Young: less than 15 years

Table 2. Effect of soil amendment and cover crops on structure and taxa richness within oasis nematode assemblages

Taxa or Family	N ± SD		Soil amendment		Cover crops	
			Organic	**Organic+mineral**	**0**	**1**
Rhabditidae	88.13	±219.37	+	+	+	+
Panagrolaimus	32.82	±35.01	+	+	+	+
diploscapter	5.21	±19.31	+	+	+	+
Acrobels	22.78	±25.98	+	+	+	+
Acrobeloides	68.15	±46.35	+	+	+	+
Cervidellus	13.79	±33.38	+	+	+	+
Plectus	0.2	±0.74	-	+	+	-
Wilsonema	1.09	±3.055	+	+	+	+
Prismatolaimus	4.06	±11.42	+	+	+	+
Rhabdolaimus	2.85	±5.52	+	+	+	+
Aphelenchus	55.61	±91.97	+	+	+	+
Aphelenchoides	21.58	±30.77	+	+	+	+
Tylencholaimus	3.25	±12.30	+	+	+	+
Pratylenchus	74.64	±71.47	+	+	+	+
Pratylenchoides	0.55	±1.58	+	-	+	+
Tylenchidae	53.95	±68.19	+	+	+	+
Tylenchorhynchus	11.75	±17.26	+	+	+	+
Tyleotylenchus	1.52	±3.49	+	+	+	-
Rotylenchus	6.19	±12.40	+	+	+	+
Helicotylenchus	0.28	±1.21	-	+	+	+
Heterodera	0.34	±1.098	+	+	+	-
Meloidogyne	16.44	±30.28	+	+	+	+
Xiphinema	0.074	±0.36	-	+	+	-
Criconema	0.2	±0.58	+	-	+	-
Trichodorus	0.053	±0.26	+	+	-	+
Quedsinematidae	4.27	±6.30	+	+	+	+
Aporcelaimidae	4.72	±5.49	+	+	+	+
Mesodorylaimus	0.41	±1.85	-	+	+	-
Eudorylaimus	0.06	±0.28	+	-	-	+
Discolaimium	0.45	±1.46	-	+	+	-
			S = 25	**S = 27**	**S = 28**	**S = 23**

0: bare soil, 1: cultivated soil (barley or alfalfa); Presence or absence of each taxa are indicated by + or -; N: nematodes/100g dry soil; S: taxa richness.

Table 3. Effect of soil tillage frequency and the last tillage before sampling on structure and taxa richness within oasis nematode assemblages

Taxa or Family	N ± SD	Tillage frequency			Last tillage		
		1 Y	2 Y	3 Y	Recent	1 Y	2 Y
Rhabditidae	88.13±219.37	+	+	+	+	+	+
Panagrolaimus	32.82±35.01	+	+	+	+	+	+
Diploscapter	5.21±19.31	-	+	+	-	+	+
Acrobels	22.78±25.98	+	+	+	+	+	+
Acrobeloides	68.15±46.35	+	+	+	+	+	+
Cervidellus	13.79±33.38	+	+	+	+	+	+
Plectus	0.2±0.74	-	+	+	-	+	+
Wilsonema	1.09±3.055	-	+	+	+	+	+
Prismatolaimus	4.06±11.42	-	+	+	+	+	+
Rhabdolaimus	2.85±5.52	-	+	+	+	+	+
Aphelenchus	55.61±91.97	+	+	+	+	+	+
Aphelenchoides	21.58±30.77	+	+	+	+	+	+
Tylencholaimus	3.25±12.30	+	+	+	-	+	+
Pratylenchus	74.64±71.47	+	+	+	+	+	+
Pratylenchoides	0.55±1.58	-	+	-	+	+	-
Tylenchidae	53.95±68.19	+	+	+	+	+	+
Tylenchorhynchus	11.75±17.26	+	+	+	+	+	+
Tyleotylenchus	1.52±3.49	+	+	+	-	+	+
Rotylenchus	6.19±12.40	+	+	+	+	+	+
Helicotylenchus	0.28±1.21	-	-	+	-	+	-
Heterodera	0.34±1.098	+	+	+	-	+	-
Meloidogyne	16.44±30.28	+	+	+	+	+	+
Xiphinema	0.074±0.36	-	-	+	-	-	+
Criconema	0.2±0.58	-	+	+	+	+	+
Trichodorus	0.053±0.26	-	+	-	+	-	-
Quedsinematidae	4.27±6.30	+	+	+	+	+	+
Aporcelaimidae	4.72±5.49	+	+	+	+	+	+
Mesodorylaimus	0.41±1.85	-	-	+	-	+	-
Eudorylaimus	0.06±0.28	-	+	-	-	+	-
Discolaimium	0.45±1.46	-	+	+	-	+	+
		S = 17	**S = 27**	**S = 27**	**S = 20**	**S = 28**	**S = 24**

S: Taxa richness; Y: year; Tillage frequency = 1Y: each 1 year, 2Y: each 2 years, 3Y: each 3 years; Last tillage = Recent: same year of sampling, 1 Y: since 1 year, 2 Y: since 2 years; N: nematodes/100g dry soil)

The MI 2-5 is and indicator of more stable environment as nematodes with higher cp values (more sensitive to soil disturbance) are more abundant in the soil sample. This index has the higher values, 2.34 and 2.35 in respectively young oases and in oases where cover crops are associated with date palm. The less index value 2.13 was found in old oases. In oases where soil is recently tilled, where soil is usually tilled each 1 year and where only manure is incorporate to soil, the MI (2-5) has relatively low values, 2.17, 2.16 and 2.18 respectively.

Among studied fields (Table 4), oases where only manure is used and where soil tillage frequency is about 2 years, the higher CI values, 29.47 and 28.7 respectively, were recorded as an indicator of fungal organic matter decomposition in these fields. However, the lower CI value was relative to young oases (15.86), to soil where both manure and chemical fertilizers are used (17.36) and to recently tilled soils (17.6). In these fields, it seems that organic matter decomposition was dominated by bacteria. The basal index (BI) is based on the abundance of general opportunistic nematodes predominantly bacterial feeder (Ba) with cp = 2 in the Cephalobidae family and fungal feeders (Fu) with cp = 2 in the Aphelenchidae, Aphelenchoididae families. It is an indicator of basal, perturbed soil food web condition. High BI values indicate a nematode assemblage composed of perturbation-resistant nematodes mainly of lower trophic levels. This index, an indicator of disturbed soil food webs, was higher in oases where soil is tilled each year and where soil was recently tilled. The community structure was, in this case, associated with fungal-dominated organic matter decomposition pathways (Table 4). The EI is based on the weighted abundance of bacterial feeding nematodes enrichment-opportunistic, indicating highly active bacterial-mediated decomposition channels. Higher values were relative to soils tilled each 3 years and to soils tilled 2 years before sampling (68.59 and 66.48, respectively) (Table 4). It showed also high values, 65.9 and 65.03 respectively, in old oases and in oases with no cover crops associated with date palm. The SI is an indicator of soil food web length and connectance, the indicator guilds of a structured soil food web include the (P) Discolaimidae and (O) Quedsinematidae (cp 5) (often considered larger Dorylaimida). Nematodes in these guilds are large-bodied, and have the lowest fecundity and longest life courses of soil nematodes**.** They are susceptible to soil disturbance and are often absent from disturbed, polluted, or intensely-managed environments (Bongers 1990; Bongers 1999).

In studied fields, the higher SI values, 43.12 and 42.89, revealing a structured food web where resources are more abundant or where recovery from stress is occurring, were recorded respectively in young oases and in oases with cover crops in association with date palm. However, in old oases and in soils where only manure was incorporated to soil, the SI showed the lowest values, 21.07 and 23.07 respectively (Table 4).

In Fig. 2, results from PCA show that nematode abundance (N) and EI are positively correlated with bare soils and with soil tilled each 3 years. Thus, the increase in nematode abundance in corresponding oases is explained by an increase in enrichment opportunist group (especially cp-1 group).

BI and CI are correlated with old oases, organic fertilizers (manure) and with soils tilled 2 years before sampling date, indicating then fungal organic matter decomposition. However, the MI (2-5) and the SI are correlated with young oases and mineral fertilizers and with soils tilled 1 year or 2 years before sampling date; in these fields food web is more structured and matured. Taxa richness (S), PPI and MI are correlated with cover cropped soils, with soils recently tilled and with soils usually tilled each 1 or 2 years (Fig. 2). The positive correlation between PPI and S reveals that the high taxa richness within studied nematode communities is reported to the high diversity in PPN population.

Table. 4: Overview on means ± SD for N (nematodes/100g dry soil), MI, MI (2-5), PPI and soil food web indix values discriminated based on oasis age and soil management

Oasis Characteristic		N	MI	MI (2-5)	PPI	BI	CI	EI	SI
Field age	Old	553.08± 632.62	1.79± 0.25	2.13± 0.10	2.63± 0.24	30.95± 14.81	26.11± 19.98	65.9± 16.12	21.07± 12.05
	Young	444.46± 142.29	2 ± 0.35	2.34± 0.22	2.76± 0.21	26.96± 11.95	15.86± 15.93	62.37± 17.77	43.12± 20.01
Cover crops	0	522.03± 500.67	1.85± 0.30	2.2± 0.16	2.67± 0.23	29.67± 14.88	21.85± 20.11	65.03± 17.28	28.25± 18.73
	1	414.92± 110.55	2.09± 0.32	2.35± 0.26	2.7± 0.27	30.99± 12.51	22.54± 16.55	56.67± 16.36	42.89± 20.47
Fertilizers	Organic	602.87± 677.70	1.88± 0.39	2.18± 0.24	2.62± 0.19	31.92± 15.49	29.47± 21.93	61.16± 18.72	23.07± 19.02
	Mineral+ organic	431.33± 151.20	1.92± 0.26	2.27± 0.16	2.72± 0.26	28.75± 13.50	17.36± 15.86	64.31± 16.46	36.98± 18.90
Tillage frequency	1 Y	337.71± 201.19	1.97± 0.050	2.16± 0.021	2.74± 0.17	40.31± 4.81	25.82± 11.99	52.95± 6.54	25.7± 2.63
	2 Y	567.55± 584.74	1.93± 0.40	2.23± 0.24	2.75± 0.20	29.87± 13.52	21.45± 16.70	61.22± 17.70	29.82± 21.24
	3 Y	453.88± 203.44	1.84± 0.22	2.25± 0.16	2.58± 0.27	27.01± 15.88	21.6± 23.72	68.59± 17.45	35.76± 20.78
Last Tillage	Recent	315.86± 135.60	1.89± 0.12	2.17± 0.06	2.86± 0.058	36.31± 11.59	17.6± 8.51	58.18± 13.66	27.26± 7.53
	1 Y	534.47± 542.26	1.94± 0.37	2.26± 0.22	2.73± 0.23	28.82± 13.52	19.91± 19.78	62.55± 17.58	33.45± 21.70
	2 Y	490.15± 192.16	1.82± 0.24	2.2± 0.16	2.49± 0.20	29.88± 16.50	28.7± 20.05	66.48± 17.88	29.33± 19.53

BI: Basal index, CI: Channel index, EI: Enrichment index, SI: Structure index, Y: year; N: nematodes/100g dry soil, MI: Maturity Index, PPI: Plant Parasitic Index.

cp triangle and faunal profile for studied nematode communities.

The classification of nematode assemblages identified in studied oases into the cp scale allows the construction of the cp triangle (Fig.3). To just depict the proportional representation of un-weighted cp-1, cp-2 and cp3-5 taxa, oases were only designated by locality name and no characteristics or agricultural management were used to discriminate them in this case. This figure reveals that most of studied oases regardless any effect of soil management type had relatively stressed soils with a high abundance of cp-1 group as an indicator of disturbed food web and few oases were characterized by a stable food web where taxa belonging to cp3-5 (susceptible to soil disturbance) were more abundant.

The faunal profile (Fig. 4) is constructed to indicate whether the soil community is basal (and inferred stressed), enriched, or structured and stable. The weighting system allows separation of the condition of food webs at different sites or at different times, based on shifts in presence and abundance of nematode taxa, with greater resolution than through the use of un-weighted cp triangles. The faunal profile in Fig. 4 representing the soil food web condition through the projection of SI vs EI, shows that among 26 studied oases, most oases had either disturbed soil (Quadrat A) relative to cp-1 group, N-enriched, with a low C/N and a degraded or depleted soil (Quadrat D) relative to cp-2 group with high C/N. Other oases were characterized by a maturing food web with N-enriched soil where the C/N was low and organic matter decomposition was bacterial; in these oases a shift from stressed to stable soil condition was occurring (Quadrat B). Among all oases only one had a matured food web where C/N was moderated, and decomposition pathway was dominated by both bacterial and fungal groups (Quadrat C). In this case the occurrence of high trophic level groups (O) and (P) is more important as they are sensitive to any soil disturbance.

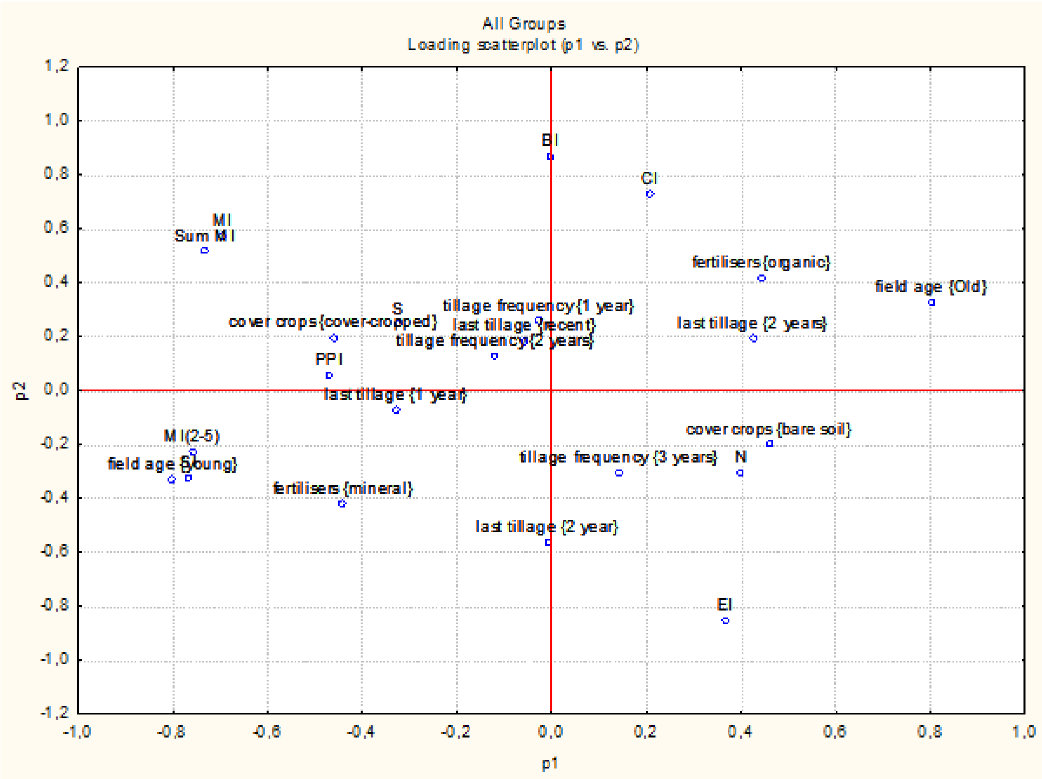

Fig. 2. Ordination of ecological indices on the biplot resulting from the Principal Component Analyses (PCA) based on the different soil managements in studied oases.

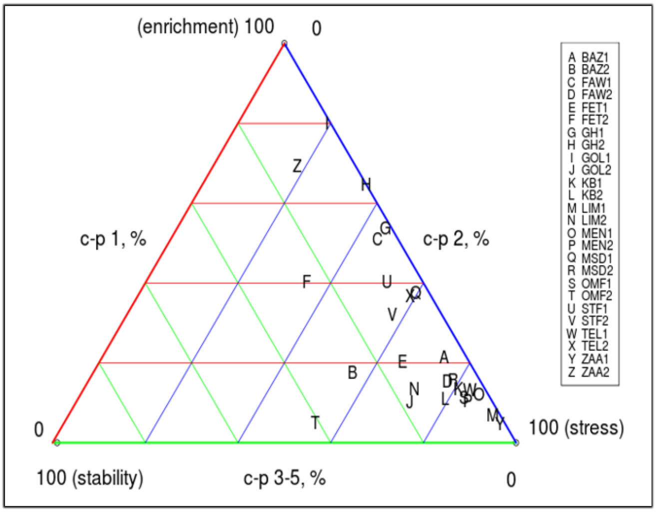

Fig. 3. cp triangle according De Goede et al. (1993) with unweighted proportional representation of cp-1, cp-2 and cp-3-5 groups of the nematode fauna in studied oases. The 13 prospected localities are indicated on the triangle by capital letters. A, B: Bazma; C, D: Fawar; E, F: Fetnassa; G, H: Ghidma; I, J: Golaa; K, L: Kebili; M, N: Limaguès, O, P: Menchiya; Q, R: M'Saaid; S, T: Om'Fareth; U, V: Esteftimi; W, X: Telmin; Y, Z: Zaafran. 1: Old oasis; 2: Young oasis.

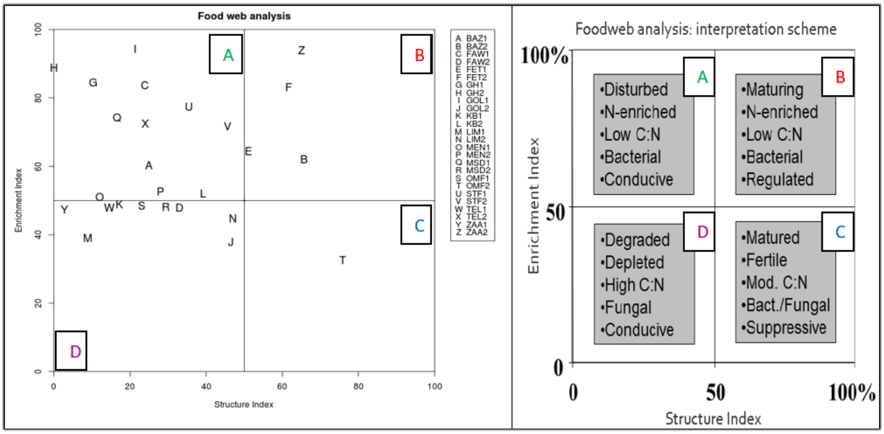

Fig. 4. Faunal profile representing the structure and enrichment conditions of the soil food web for studied oases. The 13 prospected localities are indicated on the graph by capital letters. A, B: Bazma; C, D: Fawar; E, F: Fetnassa; G, H: Ghidma; I, J: Golaa; K, L: Kebili; M, N: Limaguès, O, P: Menchiya; Q, R: M'Saaid; S, T: Om'Fareth; U, V: Esteftimi; W, X: Telmin; Y, Z: Zaafran.

DISCUSSION

Nematode populations identified from studied soils were dominated by (Ba) and (PP), as confirmed by Yeates and Bongers (1999); bacterial feeding nematodes represented the predominant feeding group of nematodes in every ecosystem and plant parasitic nematodes were the second most important group in several studied ecosystems.

In country to results of Dupont et al. (2009) indicating that fallow bare soils had less nematode abundance than cover-cropped soils, our results demonstrate that sampled bare soils showed the higher abundance and taxa richness in comparison to cover-cropped soils.

In bare studied soils, only *Trichodorus* and *Eudorylaimus* were not found, while other taxa like *Tyleotylenchus*, *Heterodera*, *Xiphinema*, *Criconema*, *Mesodorylaimus* and *Discolaimium* were absent in cover-cropped (alfalfa or barley) soils. These observations indicate that the response of the total nematode abundance to managements depends on the assemblage composition, so no general patterns can be discerned without analysing separately the taxa and functional group responses as it was reported by (Sanchèz-Moreno et al. 2006).

According to this survey, it has been confirmed that in oasis agro-ecosystem, soil amendments are usually whether the organic matter from animal source (manure) incorporated alone to soil (date palm rhizosphere) or added to other chemical fertilizers to enhance the growth and the productivity of date palm and forage associated cultures (generally barley or alfalfa)

In conventional system (manure + chemical fertilizers), taxa richness was higher than in organic system (manure). However, total nematode abundance was negatively correlated with S index in these two systems. Through this result we can conclude that the high abundance in oases under organic management is correlated with the predominance of some specific genera in the whole community. Most oases under organic system are old and characterized by a frequent and high input of manure stimulating (Ba) and (Fu) nematodes feeding on microbes involved in organic matter decomposition and mineralisation. Our observations are consistent with previous studies of (Hole et al. 2005; Liphadzi et al. 2005; Sanchèz-Moreno et al. 2006) but in contradiction with findings of Quist et al. (2016) who reported that total nematode densities in conventional and organic systems were not different. Yeates and Bongers (1999) affirmed also in this context that the nature and quantity of organic material strongly affect nematodes and usually influence the overall composition of the nematode fauna.

Studies of Neher (1999), Quist et al. (2016) and Yeates et al. (1997) confirmed that the genus *Prismatolaimus* was absent from conventional farming systems but abundant in organic systems. This result is not in correlation with that found in the current study as *Prismatolaimus* was recorded in both organic and conventional systems.

The less taxa richness was relative to soils tilled each year and in recently tilled soils. *Diploscapter, Plectus, Wilsonema, Prismatolaimus, Rhabdolaimus, Criconema, Trichodorus, Mesodorylaimus, Eudorylaimus and Discolaimium* were all absent from fields tilled each year. The highest taxa richness was reported in oases where tillage frequency is about 2 or 3 years and in soils tilled 1 year before sampling date. According to Fiscus and Neher (2002), *Plectus* is an indicator of disturbance due to the concordance between its cp value (cp-2) and its tolerance to chemical and mechanical perturbations, but we found it here more sensitive to tillage than expected from its cp value as it was absent from recently tilled soils and soils tilled each year. Sensitivity of omnivores and the predator nematode *Discolaimium* to soil tillage frequency was observed. This finding is consistent with several studies (Bongers 1999; Kladivco 2001; Mulder et al. 2003 and Sanchez-Moreno et al. 2006) where sensitivity of high trophic level nematodes (omnivorous and predators) to soil disturbance and managements was confirmed. Wardle et al. (1995) revealed that bacterial feeders are usually abundant in cultivated soils while predators and omnivores often disappear with cultivation.

From omnivores only *Mesodorylaimus* and *Eudorylaimus* were affected by soil tillage while other families seem indifferent to this soil disturbance; these different responses in the same trophic group have been reported by Porazinska et al. (1999). In addition, Postma-Blaaw et al. (2005) confirmed that nematode genera within the same trophic group can exhibit asymmetric competition, negatively influencing the abundance of other genera. Responses to perturbation may be influenced by the presence of other nematode taxa (Sanchez-Moreno et al. 2006).

A maturity index for free-living taxa (MI) may be viewed as a measure of disturbance, with lower values being indicative of a more disturbed environment and higher values characteristic of a less disturbed environment. The MI decreases with increasing microbial activity and pollution induced stress (Korenko and Schmidt 2006). Nematode groups with low cp value are considered as enrichment opportunists and therefore indicate resource availibility. Nematode groups with high cp value indicate system stability, food web complexity and connectance (Bongers 1990). The lower MI value (1,79) was recorded in old oases which is an indication of the high soil disturbance level especially where the high manure input is a common and frequent agricultural practice in these oases at Kebili. Bongers et al. (1997) reported that MI have lower value in fertilized soils than in unfertlized soils.

The PPI index responds as the inverse of the MI (Bongers et al. 1997) or has direct relationship with MI (Neher and Campbell 1994). It is based on plant parasitic nematodes. Our results showed that cover-cropped sampled soils have higher PPI than bare soils which is in correlation with findings of Ferris and Bongers (2009) who suggested that high PPI indicates vigorous host plants which reflect system enrichment while low PPI indicates poor host growth supporting nematodes assigned to lower cp values**.**

As tillage is related to soil amendments incorporation (fertilization) in oasis management system, tillage frequency and last tillage seems have the most important effect on MI and PPI variations in this study. Bongers et al. (1997) found that agricultural practices as tillage and fertilization cause a disturbance of the soil ecosystem resulting in a stimulation of bacterial and fungal activities, subsequently the soil fauna reacts by an increase of opportunist species and for nematodes by a decrease of MI and an increase of PPI, secondary successions result in a decreasing of nutrient conditions and an increasing of MI vs. decreasing of PPI (Bongers et al. 1997).

The Channel Index (CI), based on the ratio of fungivore to bacterivore nematodes, is an indicator of the prevalence of organic matter decomposition mediated by fungi. High values of the CI indicate slower, fungal-mediated, decomposition pathways while low values indicate that bacterial and rapid organic matter decomposition is occurring. In our study we can conclude that slow and fungal organic material decomposition was related with organic system with 2 years as soil tillage frequency as confirmed by Minoshima et al. (2007) who reported that no tilled soils has higher CI. Rapid bacterial decomposition was related to conventional system and to recently tilled soils. Most of oases under organic system are old oases and farmers are used to accumulate date palm residues on soil surface and use manure as amendments; this can explain the slow organic matter decomposition mediated by fungi found in these oases.

RESUME

Larayedh-Bettaieb, A., Hajji-Hedfi, L., Sanchèz-Moreno, S., Chihani-Hammas, N., Regaieg, H., Aoun, F., Horrigue-Raouani, N. et Belkadhi, M, S. 2018. Effets de la gestion du sol sur la biodiversité des communautés de nématodes en tant qu'indicateur biologique de la qualité des sols dans l'agro-écosystème oasien de Kebili. Tunisian Journal of Plant Protection 13 (2): 183-200.

Les communautés de nématodes du sol ont été étudiées dans 26 oasis du sud tunisien (Kébili) caractérisées par différentes pratiques culturales. Les oasis étudiées ont été discriminées selon la fréquence du travail du sol, le type d'amendement du sol (fumier ou fumier + engrais), les cultures en association avec le palmier dattier et l'âge de l'oasis. En outre, cette étude a évalué l'importance du triangle C-P (Colonisateur-Persistant) et du profil faunistique (représentation de l'indice d'enrichissement vs. L'indice de structure) en tant qu'indicateur biologique et un outil de surveillance à l'appui de l'évaluation de la qualité du sol. Les résultats ont montré que les communautés de nématodes étaient composées de 10 genres bactériophages (Ba), 3 mycophages (Fu), 12 phytoparasites (PP), 4 omnivores (O) et 1 prédateur (P) avec une dominance de (Ba) et (PP) dans toutes les oasis. Les communautés de nématodes différaient légèrement en fonction de l'âge de l'oasis. Les bactériophages et le genre *Discolaimium* ont été trouvés dans les anciennes et les nouvelles oasis. Le genre *Plectus* (Ba) n'a été trouvé que dans les nouvelles oasis alors que les genres *Xiphinema*, *Criconema* et *Trichodorus* (PP) étaient absents dans ces oasis. Seuls quelques genres ont été affectés par le type d'amendements du sol et les cultures associées, y compris certains bactériopahges et mycophages. La richesse générique la plus élevée a été enregistrée dans les oasis à sols nus et dans les oasis où la fréquence de travail du sol était de 2 ou 3 ans. La plus faible valeur de l'indice de maturité (IM) a été enregistrée dans les anciennes oasis. Le profil faunistique représentant les conditions de structure et d'enrichissement de la chaine alimentaire dans les sols oasiens prospectés montre bien que la plupart des oasis étudiées étaient caractérisées soit par un niveau élevé de perturbation du sol avec une abondance élevée du groupe à valeur c-p = 1 en tant qu'indicateur d'un réseau trophique perturbé, soit par un sol stressé avec une densité élevée du groupe à valeur c-p = 2 comme indicateur d'un réseau trophique dégradé. Seuls quelques sites ont montré des réseaux trophiques structurés ou en cours de maturation avec des niveaux de perturbation du sol respectivement faibles à modérés et des sols non perturbés. Cette étude a mis en évidence que certains genres de nématodes pourraient potentiellement servir comme des bio-indicateurs différentiels de la perturbation du sol.

Mots Clés: Biodiversité, communautés des nématodes, indices écologiques, oasis, palmier dattier, pratiques culturales, sol

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ملخص

لعريض-بالطيب، أسماء ولبنى حاجي-هادفي وساره سانشز-مورينو ونورة شيهاني-حماص وهاجر رفيق وفوزي عون ونجاة حريق-رواني ومحمد الصادق بالقاضي. 2018. تأثير إدارة التربة على التنوع الحيوي لمجتمعات النيماتودا كمؤشر بيولوجي لجودة التربة في النظام البيئي-الزراعي بواحات قبلي.

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تمت دراسة تجمعات نيماتودا التربة في 26 واحة بالجنوب التونسي تحت أنظمة زراعية مختلفة. تكمن الاختلافات بين الواحات المدروسة في كثافة حراثة التربة، نوع الأسمدة (السماد العضوي أو السماد العضوي مع الأسمدة المعدنية)، الزراعات المرتبطة بالنخيل وعمر الواحة. بالإضافة إلى ذلك ، قيمت هذه الدراسة أهمية مثلث C-P (المستعمر- المستمر) و التنميط المجتمعي (تمثيل مؤشر الإثراء IE مقابل المؤشر الهيكلي IS) لنيماتودا التربة كمؤشر بيولوجي وأداة لتقييم جودة التربة. أظهرت النتائج أن تجمعات نيماتودا التربة كانت تتكون من 5 أصناف مقسمة حسب نوعية النظام الغذائي: 10 أنواع تتغذى على البكتيريا، 3 أنواع تتغذى على الفطريات، 12 نوع يتغذى على جذور النباتات، 4 أنواع تتغذى على الكائنات الدقيقة المختلفة في التربة ونوع واحد مفترس يتغذى على النيماتودا مع ملاحظة هيمنة الصنفين الأولين في جميع الواحات التي تمت دراستها. اختلفت مجتمعات هذه النيماتودا بدرجة قليلة بالاعتماد على عمر الواحة. تم العثور على النيماتودا المتغذية على البكتيريا و النوع *Discolaimium* في كلا الواحات القديمة والحديثة. تم عزل النوع *Plectus* فقط في الواحات الحديثة في حين كانت الأنواع *Xiphinema* و *Criconema* و*Trichodorus* غائبة في هذه الواحات. تأثرت القليل من أنواع النيماتودا بنوع الأسمدة و بالزراعات المرتبطة بالنخيل بما في ذلك بعض أنواع النيماتودا المتغذية على البكتيريا وعلى الفطريات. تم تسجيل أعلى نسبة تنوع صنفي في الواحات التي لا توجد بها زراعات مرتبطة بالنخيل وفي الواحات التي تتميز بكثافة حراثة تربة منخفضة (كل عامين أو 3 أعوام). تم تسجيل أدنى معدل للمؤشر MI في الواحات القديمة. اتسمت معظم الواحات المدروسة إما بتربة مضطربة تتميز بوفرة كبيرة للمجموعة cp-1 كمؤشر على شبكة غذائية مضطربة أو بتربة مرهقة تتميز بوفرة كبيرة للمجموعة cp-2 كمؤشر على شبكة غذائية متدهورة. أظهر عدد قليل فقط من الواحات المدروسة شبكات غذائية ناضجة ومنظمة ذات مستوى تآكل تربة منخفض إلى معتدل و تربة غير مضطربة على التوالي. أوضحت هذه الدراسة أن بعض أجناس النيماتودا يمكن أن تستعمل بمثابة مؤشرات بيولوجية تفاضلية لتقييم درجة اضطراب التربة.

كلمات مفتاحية: تجمعات نيماتودا، تربة، تنوع بيولوجي، مؤشرات بيئية، نخيل تمر، نظام زراعي، واحات

LITERATURE CITED

Barker, K., Carter, C., and Sasser, J. 1985. Nematode extraction and bioassays. Pages 19-35. In: An Advance Treatise of *Meloidogyne*. K.R. Barker, C.C. Carter and J.N. Sasser, Ed. Editions 2. State University Graphics, Raleight, NC, North Carolina, USA.

Berkelmans, R., Ferris, H., Tenuta, M., and Van Bruggen, A.H.C. 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.

Bongers, T. 1988. De Nematoden van Nederland. KNNV BibliotheekUitgeverijPirola, Schoorl, Nederland, 408pp.

Bongers, T. 1990. The maturity index: An ecological measure of environmental disturbance based on nematode species composition. Oecologia 83: 14-19.

Bonger, T. Van der Mulen, H., and Korthals, G. 1997. Inverse relationship between the nematode maturity index and plant parasitic index under enriched nutrient conditions. Appl. Soil Ecol. 6: 195-199.

Bongers, T., and Ferris, H. 1999. Nematode community structure as a bioindicator in environmental monitoring, Trends Ecol. Evol. 14: 224-228.

Bongers, T., van der Meulen, H., and Korthals, G. 1997. Inverse relationship between the nematode maturity index and plant parasite index under enriched nutrient conditions. Applied Soil Ecology 6(2):195-199.

Bongers, T. 1999. The Maturity Index, the evolution of nematode life history traits, adaptive radiation and cp-scaling. Plant Soil 212: 13-22.

De Goede, R.G.M., Verschoor, B.C., and Georgieva, S.S. 1993. Nematode distribution, trophic structure and biomass in a primary succession of blown-out areas in a drift sand landscape. Fundam. Appl. Nemalol. 16 (6): 525-538.

Dupont, S.T., Ferris, H., and Van Horn, M. 2009. Effects of cover crops quality and quantity on nematode-based soil food webs and nutrient cycling. Applied Soil Ecology 41: 157-167.

Ettema, C.H., Coleman, D.C., Vellidis, G., Lowrance, R., and Rathbun, S.L. 1998. Spatiotemporal distributions of bacteriovorous nematodes and soil resources in a restored riparian wetland. Ecology 79: 2721-2734.

Ferris, H., and Bongers T. 2009. Indices for analysis of nematode assemblages. Pages 124-145. In:Nematodes as Environmental Biondicators. M. Wilson, T. Kakouli-Duarte, Ed. Wallingford: CABI, U.K.

Ferris, H., Bongers, T., and De Goede, R.G.M. 2001. A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. Applied Soil Ecology 18: 13-29.

Ferris, H., Venette, R.C., and Scow, K.M. 2004. Soil management to enhance bacterivore and fungivore nematode populations and their nitrogen mineralisation function. Applied Soil Ecology 25: 19-35.

Fiscus, D.A., and Neher, D.A. 2002. Distinguishing sensitivity of free-living soil nematode genera to physical and chemical disturbances. Ecological Applications 12: 565-575.

Hole, D.G., Perkins, A.J., Wilson, D.J., Alexander, I.H., Grice, P.V., and Evans, A.D. 2005. Does organic farming benefit biodiversity? Biol. Conserv. 122: 113-130.

Korenko, V., and Schmidt, C. 2006. Effects of agricultural practices in the rice crop system on nematode communities in Uruguay. NematologiaMediterranea 34: 151-159.

Korthals, G.W., Alexiev, A.D., Lexmond, T.M., Kammenga, J.E., and Bongers, T. 1996. Long-term effects of copper and pH on the nematode communityin an agroecosystem.Environmental Toxicology and Chemistry 15: 979-985.

Kladivco, E.J. 2001. Tillage systems and ecology. Soil and tillage research 61:61-76

Liphadzi, K.B., Al- Khatib, K., Bensch, C., Stahlman, P.W., Dille, J.A., Todd, T., Rice, C.W., Horak, M.J., and Head, G. 2005. Soil microbial and nematode communities as affected by glyphosate and tillage practices in a glyphosate-resistant cropping system. Weed Science53: 536- 545.

Mulder, C., De Zwart, D., Van Wijnen, H.J., Schouten, A.J., and Breure, A.M. 2003. Observational and simulated evidence of ecological shifts within the soil nematode community of agroecosystems under conventional and organic farming. Functional Ecology17: 516-525.

Neher, D.A. 1999. Nematode communities in organically and conventionnaly managed agricultural soils.Journal of Nematology 31: 142-154.

Neher, D.A. 2010. Ecology of plant and free-living nematodes in natural and agricultural soil. Ann Rev Phytopathol 48: 371–394.

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

Quist, C.W., Schrama, M., De haan, J.J., Smant, G., Bakker, J., Van der Putten, W.H., and Helder, J. 2016. Organic farming practices result in compositional shift in nematode communities that exceed crop-related changes. App.Soil.Ecol. 98: 254-260.

Pen-Mouratov S., Shukurov N., and Steinberger, Y. 2010. Soil free-living nematodes as indicators of both industrial pollution and livestock activity in Central Asia. Ecol. Indic. 10:955-967.

Porazinska, D.L., Duncan, L.W., McSorley, R., and Graham, J.H. 1999. Nematode communities as indicators of status and processes of soil ecosystem influenced by agricultural management practices. App.Soil Ecol. 13: 69-86.

Sanchez-Moreno, S., Minoshima, H., Ferris, H., and E.Jackson, L. 2006. Linking soil properties and nematode community composition: effects of soil managements on soil food webs. Nematology 8(5): 703-715.

Sanchèz-Moreno, S., and Navas A. 2007. Nematode diversity and food web condition in heavy metal pollutes soils in river basin in southern Spain. Eur. J. Soil Biol. 43:166-179.

Sieriebriennikov, B., Ferris, H., and De Goede, R.G.M. 2014. NINJA: an automated calculation system for nematode-based biological monitoring. Eur. J. Soil Biol. 61: 90-93.

StatSoft, I.1996. STATISTICA for Windows (Computer Program Manual). Tulsa, OK, 74104, USA.

Timper, P., 2014. Conserving and Enhancing Biological Control of Nematodes. Journal of Nematology46 (2): 75-89.

Wardle, D.A., Yeates, G.W., Watson, R.N., and Nicholson, K.S. 1995. The detritus food web and the diversity of soil fauna as indicators of disturbance regimes in agro-ecosystems. Plant and Soil 170: 35–43.

Yeates, G.W. 2003. Nematodes as soil indicators: functional and biodiversity aspects. Biology and Fertility of Soils 37: 199-210.

Yeates, G.W., Bongers, T., de Goede, R.G.M., Freckman, D.W., and Georgieva, S.S. 1993. Feeding habits in soil nematode families and

genera - an outline for soil ecologists. Journal of Nematology 25: 315-331.
Yeates, G.W., Bardgett,R.D., Cook, R., Hobbs, P.J., Bowling, P.J., and Potter, J.F. 1997. Faunal and microbial diversity in three Welsh grassland soils under conventional and organic amendments regimes. J. App.Ecol. 34: 453-470.
Yeates, G.W., and Bongers, T. 1999. Nematode diversity in agroecosystems. Agriculture, Ecosystems and Environment 74: 111-115.
