Vertical distribution of soil free-living nematode in a playa habitat in the North-Western Negev desert, Israel

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Summary

In order to investigate the vertical distribution of soil nematode community under a playa area in the Nizzana inter-sand dune area in the north-western Negev Desert of Israel, soil samples were collected from 0 – 10, 10 – 20, 20 – 30, 30 – 40, and 40 – 50 cm depths in the playa and loessial plain area (as control) during the dry and wet seasons. Each of soil samples was determined for soil moisture, organic matter concentration, electrical conductivity, and nematode community structure and biodiversity. The results revealed that soil moisture, organic matter, electrical conductivity, total nematode abundance and trophic groups were significantly influenced by sampling positions ($P < 0.0001$) and depths ($P < 0.05$) and significant interaction effect of position and depth ($P < 0.05$) was also found. Total number of nematodes in the playa area ranged from 1 to 15 individuals per 100 g dry soil, whereas they ranged from 60 to 631 individuals per 100 g dry soil in the loessial plain area. The greatest nematode number was found in 0 – 10 cm soil depth and the lowest nematode number was found in 40 – 50 cm soil depth. Total number of nematodes, bacterivores, fungivores, plant parasites and omnivores-predators were significantly ($P < 0.05$) greater in the loessial plain area than that in the playa area in all sampling depths under the dry and wet seasons. Total thirteen genera were found in the playa area, with *Acrobeloides* as the dominant genus, whereas there were fifty-five genera, with *Acrobeles* as the dominant genus in the loessial plain area. Nematode ecological indices, such as fungivores/bacterivores ratio (F/B), nematode channel ratio (NCR), trophic diversity (T), Shannon Index (H'), genus dominance (λ), species richness (SR), maturity index (MI), modified maturity index (MMI), Enrichment Index (EI) and Structure Index (SI) were significantly ($P < 0.01$) differentiated between sampling locations. As conclusion, soil free-living nematode inhabited mostly the upper soil layers (0 – 20 cm) and the number of nematode had gradually decreasing trend with soil depths increasing in the playa area. Moreover, each soil layer had a little nematode abundance and community diversity in the playa area in contrast to loessial plain area during the dry and wet seasons. Sampling sites and depths significantly effected on soil properties, nematode abundance and trophic groups, but nematode ecological indices were affected only by sampling sites.

Keywords: vertical distribution; soil nematode community; biodiversity; playa area; loessial plain area

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Introduction

Inter-sand dune desert sites are known to be among the most prominent locations for generating playa surfaces characterized by compact floors, salt pavements, carbonate surfaces, and a high percentage (50 % or more) of clay lacking microbiotic crusts (Breckle *et al.*, 2008; Yu *et al.*, 2012). Most of the playa area lack vegetation cover and are classified as a *Solonchaks* soil type which is known as a typical soil profile with a takyric surface (Pen-Mouratov *et al.*, 2011). Such physical and chemical soil properties have a strong influence on the vertical flow of water by playing a crucial function in soil biotic community composition, density, and diversity (Kidron & Yair, 2001; Guan *et al.*, 2015; Siebert *et al.*, 2019). Soil nematode community is known to be among the important components of soil fauna, by being of great abundance (>3 million m⁻² at some sites) (Yeates, 2003; Liu *et al.*, 2019). Moreover, due to their feeding behavior they can be divided into at least five trophic groups or functional guilds (Yeates *et al.*, 1993; Hu *et al.*, 2018). Therefore, they are regarded as fulfilling a central position in the soil detritus food web (Neher, 2001). Due to their various trophic property, soil free living nematodes are a great bioindicator in the soil and can respond to sand soil environmental changes (Wall *et al.*, 2002; Jiang *et al.*, 2007; Zhang *et al.*, 2009).

Most of the studies on sand dune ecosystems have been oriented toward coastal sand dunes. For example, Goralczyk (1998) studied the nematode population as bioindicators in a coastal sand dune elucidating their importance as good indicators in the plant succession process in bare dunes. Wall *et al.* (2002) observed that soil nematode abundance, diversity, trophic structure and composition were related to soil factors along a coastal sand dune succession. Liang *et al.* (2005) studied the vertical distribution of bacterivorous nematodes under different land uses. Ou *et al.* (2005) investigated the vertical distribution of soil nematodes in an aquic brown soil of China. Jiang *et al.* (2007) studied the vertical distribution of soil nematodes in the Horqin Sandy Land, Northeast China. Pen-Mouratov *et al.* (2008b) observed the vertical distribution of soil free-living nematode communities in the Tehuacán Desert, Mexico. Zhang *et al.* (2010) reported the spatial distribution of soil nematode communities in stable and active sand dunes of Horqin Sandy Land. Yang *et al.* (2018) studied the impact of human trampling on nematode community in a desert ecosystem.

An important gap in the knowledge on the soil free living nematode community structure in desert inter-sand dune ecosystem raised our interest, due to a unique combination between a xeric environment and sandy soil physical characteristics. Furthermore, two main biotopes can be found in this unique inter-dune area: the playa system is characterized by a thick crust with low water infiltration and the sandy system with high water infiltration rates. Moreover, due to the lack of moisture, unpredictability followed by different rates of water infiltration between the two systems, the food randomness availability for the nematode community becomes even more critical. Therefore, the vertical distribution of

the nematode community and its trophic composition aspect were found to be even more inspiring.

The aim of this study was to determine the vertical distribution of soil free living nematode community representing a playa and a loessial plain area in a desert inter-sand dune ecosystem under two – wet and dry – extreme environmental conditions in the North-Western Negev Desert, Israel.

Materials and Methods

Study site

Study site (30°53'14"N, 34°25'15"E) is located at the Nizzana sand dune site within the Hallamish dune field eastern extension of the northern Sinai dune field – western Negev Desert, Israel (Yair, 1990). The dune field comprises longitudinal dunes aligned west-east, are 15 to 20 m high and are separated by a 50 m to 200 m wide interdune. The Nizzana experimental site is located about 45 km inland from the Mediterranean Sea. Mean annual precipitation is 95 mm and occurs during the winter months (November – April) and the average monthly temperatures are 9°C in January and 25°C in August. Potential annual evaporation is in the order of 2200 mm (Kidron, 2001; Kidron & Yair, 2001; Keck *et al.*, 2016).

The playa area is a geomorphological inter-sand dune desert site unit comprised of thin, dense layers (1 – 2 mm thick) covered with dark brown clay skins, followed by 3 cm of angular blocky, deeper down, single grained sandy layers, with very few tubules and holes, alternating with loamy units, having a massive blocky structure (Kidron *et al.*, 2009). All layers are nearly horizontal with textural boundaries, indicating a sedimentary origin and playa area soil rich in clay and silt and have low or no vegetation cover (Yair, 1990). The rusty mottles show that anaerobic conditions with stagnant water occur from time to time (Pen-Mouratov *et al.*, 2011). The clayey layers are dense with pore sizes mainly in the range of 10 – 50 µm, thus retarding water infiltration and movement. Carbonate content at such places may exceed 30 %, with an alkaline pH. These geomorphological formations are surrounded by a sandy loessial plain area. This plain area soils have a surface crust, which is classified as a platy surface structure, with shallow cracks 1 – 2 mm deep filled with windblown sand. The lower part of the crust has a vesicular structure. The distribution of vegetation is mainly the perennial Chenopodiaceous species, *Anabasis articulata* in the inter-sand dune valley (Breckle *et al.*, 2008).

Sampling

Soil samples were collected at the study site at the end of the summer season, representing the driest period and in the middle of the winter season, representing the wet season, using a 7-cm diameter soil auger. Soil samples from the 0 to 50 cm at 10 cm intervals (corresponding to 0 – 10, 10 – 20, 20 – 30, 30 – 40, and 40 – 50 cm depths, four replicates) were randomly collected from both playa and loessial plain areas (as control). Each of the soil samples was deposited in an individual plastic bag which was

Table 1. Soil physico-chemical properties in the playa and loessial plain areas (as control) under the dry and wet seasons.

Treatment	Dry season			Wet season		
	SM (%)	OM (%)	EC (ms cm ⁻¹)	SM (%)	OM (%)	EC (ms cm ⁻¹)
0 – 10 cm						
playa	1.28±0.73a**	0.25±0.05a	2.20±1.15a	7.16±1.70a	0.14±0.07a	1.97±0.63a
loessial plain	0.11±0.05b	0.07±0.04b	0.05±0.00b	1.93±0.54b	0.05±0.04b	0.08±0.01b
10 – 20 cm						
playa	2.42±0.68a	0.18±0.03a	3.35±0.59a	5.44±0.53a	0.16±0.13a	1.77±0.32a
loessial plain	0.09±0.03b	0.07±0.04b	0.05±0.00b	1.14±0.15b	0.04±0.03a	0.07±0.01b
20 – 30 cm						
playa	3.08±0.95a	0.13±0.03a	3.03±0.75a	6.75±0.89a	0.14±0.07a	2.85±0.97a
loessial plain	0.13±0.03b	0.06±0.06b	0.05±0.00b	0.84±0.17b	0.02±0.00b	0.07±0.01b
30 – 40 cm						
playa	3.81±1.05a	0.10±0.02a	2.99±0.68a	5.69±0.90a	0.15±0.08a	2.63±0.39a
loessial plain	0.16±0.06b	0.03±0.02b	0.06±0.01b	0.80±0.17b	0.02±0.00b	0.06±0.00b
40 – 50 cm						
playa	1.23±1.35a	0.04±0.04a	1.09±0.75a	3.47±1.65a	0.10±0.05a	1.83±0.80a
loessial plain	0.42±0.40a	0.05±0.05a	0.06±0.03b	0.80±0.12b	0.04±0.01b	0.07±0.01b

*SM: soil moisture; OM: soil organic matter content; EC: electrical conductivity.

**Means and standard deviation from four replicates, different letters at each soil layer in a column denote significant differences as assessed by *t*-test ($P < 0.05$).

placed in an insulated container and transported to the laboratory. These soil samples were kept in cold storage at 4 °C until processing. All soil samples were sieved (2 mm mesh size) before biological and chemical analysis in order to remove root particles and other organic debris.

Laboratory analysis

Soil moisture – was determined gravimetrically by drying the samples at 105 °C for 48 h. The values were expressed as percentage of dry weight.

Organic matter concentration – was determined by oxidation dry soil sample with dichromate in the presence of H₂SO₄, without application of external heat (Rowell, 1994).

Electrical conductivity – was determined on a 5 g subsample that was agitated (half-hour at room temperature) with 50 ml distilled water. The filtrated solution was analyzed using a TH-2400 conductivity meter (ms cm⁻¹).

Soil free-living nematodes – were extracted from 100 g fresh soil samples using the Baermann funnel procedure (Cairns, 1960) and nematode populations were expressed per 100 g dry mass soil. The recovered organisms were counted and preserved in formalin (Steinberger & Sarig, 1993). Total one hundred individuals from each samples were randomly picked and used for identification to genus level, according to esophageal and morphology character-

istics using an inverted compound microscope (Mal & Lyon, 1975; Ying, 1998).

Nematode ecological indices calculation and data statistical analysis

The data were analyzed using the following approaches: (1) total nematode number in 100 g⁻¹ dry soil (TN); (2) trophic groups, including bacterivores (BF), fungivores (FF), plant parasites (PP), omnivores–predators (OP) (Yeates, *et al.*, 1993; Liang *et al.*, 1999; Pen-Mouratov *et al.*, 2004); (3) F/B, fungivores/bacterivores ratio (Twinn, 1974); (4) NCR, nematode channel ratio, where $NCR = BF / (BF + FF)$ (Yeates, 2003); (5) T, trophic diversity, $T = 1 / \sum p_i^2$, in which p_i is the proportion of the *i*-th trophic group in the nematode community (Heip *et al.*, 1988); (6) H', Shannon Index, $H' = -\sum p_i (\ln p_i)$, where p_i is the proportion of individuals in the *i*-th taxon (Shannon & Weaver, 1949); (7) Simpson index for dominance (λ), where $\lambda = 1 / \sum p_i^2$ (Simpson, 1949); (8) SR, species richness, $SR = (S - 1) / \ln(N)$, where S is the number of taxa and N is the number of individuals identified (Yeates & King, 1997); (9) MI, maturity index, $MI = \sum v_i p_i$, where v_i is the c-p value for free-living nematodes assigned by Bongers (1990) to the *i*-th nematode genus and p_i is the proportion of the genus in the nematode community; (10) MMI, modified maturity index, including plant-feeding nematodes, $MMI = \sum v_i p_i$, where v_i is the c-p value for free-living and plant parasitic

Table 2. Univariate analysis of variance of the soil properties, nematode population and ecological indices.

Index	Location (L)		Depth (D)		Season (S)		L×D		L×S		D×S	
	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Soil properties												
SM [*]	139.81	< 0.0001	6.36	0.0002	139.81	< 0.0001	7.12	< 0.0001	45.04	< 0.0001	6.80	0.0001
OM	1.16	< 0.0001	4.95	0.0016	1.16	NS	2.72	0.0376	0.54	NS	1.64	NS
EC	1.73	< 0.0001	5.25	0.0011	1.73	NS	5.35	0.0009	2.02	NS	2.45	NS
Trophic group												
TN	69.36	< 0.0001	6.42	0.0002	8.88	0.0042	6.21	0.0003	7.63	0.0076	1.08	NS
BF	49.67	< 0.0001	4.39	0.0035	6.80	0.0115	4.17	0.0048	5.48	0.0226	1.24	NS
FF	24.00	< 0.0001	3.67	0.0097	4.44	0.0394	3.65	0.0100	4.22	0.0443	0.92	NS
PP	36.87	< 0.0001	3.63	0.0102	1.87	NS	3.63	0.0103	1.87	NS	2.10	NS
OP	45.42	< 0.0001	3.68	0.0096	4.22	0.0442	3.66	0.0099	4.14	0.0462	0.69	NS
Ecological indices												
F/B	8.71	0.005	0.76	NS	0.48	NS	0.34	NS	1.19	NS	0.52	NS
NCR	17.50	0.0001	0.66	NS	0.63	NS	0.39	NS	1.16	NS	0.63	NS
T	55.27	< 0.0001	0.57	NS	0.78	NS	0.51	NS	0.53	NS	0.50	NS
H'	618.16	< 0.0001	1.29	NS	22.40	< 0.0001	1.69	NS	23.27	< 0.0001	0.76	NS
λ	177.50	< 0.0001	0.93	NS	2.82	NS	1.79	NS	20.50	< 0.0001	0.41	NS
SR	139.82	< 0.0001	0.36	NS	3.39	NS	1.25	NS	8.16	0.0062	0.45	NS
MI	22.25	< 0.0001	1.74	NS	1.24	NS	2.71	0.0417	5.07	0.0292	1.84	NS
MMI	12.18	0.001	1.27	NS	0.95	NS	2.20	NS	0.33	NS	0.51	NS
EI	9.75	0.0032	1.69	NS	5.78	0.0206	0.41	NS	0.01	NS	0.14	NS
SI	22.56	< 0.0001	0.56	NS	1.66	NS	3.08	0.0253	11.82	0.0013	1.85	NS

*SM: soil moisture; OM: organic matter; EC: electrical conductivity; TN: total number of nematodes; BF: bacterivores; FF: fungivores; PP: plant-parasite nematodes; OP: omnivore-predator nematodes; F/B: fungivores/bacterivores ratio; NCR: nematode channel ratio T: trophic diversity; H': Shannon index; λ: genus dominance; SR: species richness; MI: maturity index; MMI: modified maturity index; EI: enrichment index; SI: structure index. NS: no significant.

nematodes assigned by Bongers (1990) to the i -th nematode genus and p_i is the proportion of the genus in the nematode community (Yeates, 1994); (11) EI, Enrichment Index is calculated as $EI = 100(e/(e+b))$, where e is the abundance of individuals in guilds in the enrichment component weighted by their respective k_e values and b is the abundance of individuals in the basal component weighted by their k_b values (Ferris *et al.*, 2001; 2004; Ferris & Matute, 2003); (12) SI, Structure Index is calculated as $SI = 100(s/(s+b))$, where s is the abundance of individuals in the structure component weighted by their k_s values.

All obtained data were subjected to statistical analysis of variance (ANOVA) using the SAS model (GLM, Duncan's multiple range test and Pearson correlation coefficient) and were used to evaluate differences between separate means. CANOCO redundancy analysis (ter Braak & Prentice 1996; ter Braak & Smilauer 2002) were used to evaluate the relationship among nematode trophic

groups, soil depths and environmental variables. Differences obtained at levels of $P < 0.05$ were considered significant.

Ethical Approval and/or Informed Consent

This study is neither related to human nor animals use.

Results

Soil physico-chemical properties

Soil moisture reached a maximum value of 7.2 % in the 0 – 10 cm soil layer at the playa site in the wet season, whereas a minimum value of 0.1 % was found in the dry season in the 0 to 20 cm soil layer in the loessial plain area. Soil moisture in the playa area was significantly ($P < 0.05$) higher than that in the loessial plain area during the dry and wet seasons (Table 1). Moreover, the univariate

Fig. 1. Vertical distribution of total number of nematode at five soil depths in the playa and loessial plain areas during the dry and wet seasons. PD-playa area during the dry season; PW-playa area during the wet season; CD-loessial plain area during the dry season; CW-loessial plain area during the wet season.

analysis elucidated a significant ($P < 0.001$) effect of the different factors, such as: sampling location, depth, season and interaction between them, except the combination of three of the factors (Table 2).

Soil organic matter content was found to reach a maximum value in the 0 – 10 cm layer in the playa site under dry the season and a minimum in the 20 – 40 cm soil layer in the loessial plain area during the wet season. Moreover, general high values were in the playa soil samples (Table 1). Significant difference in soil organic matter content were found by location ($P < 0.0001$) and depth ($P < 0.01$), rather than by seasonality (Table 2).

Soil electrical conductivity was found to follow the soil organic matter trend, with significantly ($P < 0.0001$) (Table 1) higher values in the playa area during the dry season than that in the loessial plain area during both seasons. Soil electrical conductivity was also significantly influenced by location ($P < 0.0001$) and depth ($P < 0.01$) (Table 2).

Total number of nematode

Total number of nematode in the playa area ranged from 1 to 15 individuals per 100 g dry soil, while total number of nematode in the loessial plain area was many fold higher, ranging from 60 to 631 individuals per 100 g dry soil and resulting in significant ($P < 0.0001$) differences between the sampling sites (Fig. 1). Moreover, total nematode abundance of every soil layer in the loessial plain area was significantly ($P < 0.0001$) higher than that in the playa area during the dry and wet seasons. The upper soil layers were represented by a higher nematode abundance and the number of nematode had gradually decreasing trend with soil depths increasing at both sampling sites and seasons. In general, total number

of soil free living nematode was significantly affected by sampling locations ($P < 0.0001$), depths ($P < 0.001$) and seasons ($P < 0.01$) on (Table 2). Total soil free living nematode was found to be significantly negatively correlated with soil moisture, soil organic matter content and electrical conductivity, respectively (Table 3).

Nematode trophic groups

The general pattern obtained for the changes in total soil free living nematode were found to be reflected in the trophic group abundance. Bacterivores were found to be the dominant trophic group in the present study, and they were significantly greater ($P < 0.05$) in the loessial plain area than that in the playa area in each layer during the dry and wet seasons. In the playa and loessial plain area, bacterivores in the upper soil layer (0 – 10cm) was greater than in the other layers during the dry and wet seasons (Fig. 2). In general, bacterivores were significantly affected by sampling locations ($P < 0.0001$), depths ($P < 0.01$) and seasons ($P < 0.05$) (Table 2). Bacterivores exhibited a significant negative correlation with soil moisture and electrical conductivity (Table 3).

Fungivores were found in lower numbers, whereas the pattern of their behavior was found to replicate that of the bacterivores, with a relatively higher population size in the loessial plain area than in the playa area in all sampling depths and season (Fig. 2). In the upper 0 – 10 cm soil layer in the loessial plain area, the fungivores had a higher abundance during the dry and wet season. Furthermore, the overall data revealed that the sampling locations ($P < 0.0001$), depths ($P < 0.01$) and seasons ($P < 0.05$) significantly effected on their number (Table 2). Fungivores manifested a significant negative correlation with soil moisture and electrical conductivity (Table 3).

Table 3. Correlation coefficients between soil properties and soil nematode indices.

Index	SM	OM	EC
TN [†]	- 0.44***	- 0.23 [*]	- 0.51***
BF	- 0.41***	NS	- 0.48***
FF	- 0.33**	NS	- 0.37***
PP	- 0.36**	- 0.2 [*]	- 0.44***
OP	- 0.43***	- 0.25 [*]	- 0.48***
F/B	- 0.28 [*]	NS	NS
NCR	0.36**	NS	0.35**
T	- 0.52***	- 0.44***	- 0.58***
H [*]	- 0.77***	- 0.54***	- 0.78***
λ	0.74***	0.47***	0.70***
SR	- 0.6***	- 0.57***	- 0.72***
MI	- 0.56***	- 0.42***	- 0.42***
MMI	- 0.40***	- 0.35**	- 0.32**
EI	NS	NS	- 0.39**
SI	- 0.58***	- 0.44***	- 0.47***

[†]Abbreviations as in Table 2. NS: no significant. *, **, *** Correlation coefficients significant at $P < 0.05$, 0.01 and 0.001, respectively.

Plant-parasitic nematodes were the least trophic group (Fig. 2). Plant-parasitic nematodes were significantly affected by sampling locations ($P < 0.0001$) and depths ($P < 0.05$) (Table 2) and significantly negatively correlated with soil moisture, soil organic matter content and electrical conductivity (Table 3).

Omnivores-predators were found to follow bacteria-feeding and fungi-feeding trophic groups, with a higher abundance in the loessial plain area and in the 0 – 20 cm soil layer (Fig. 2). Omnivores-predators were significantly influenced by sampling locations ($P < 0.0001$), depths ($P < 0.01$) and seasons ($P < 0.05$) (Table 2). Omnivores-predators were significantly negatively correlated with soil moisture, soil organic matter content and electrical conductivity (Table 3).

RDA analysis revealed that BF and OP were mainly distributed within the 0 – 10 cm depth and PP mainly in the 10 – 20 cm and 20 – 30 cm depths in the playa area during the dry season (Fig. 3). BF and PP were mainly distributed in the 0 – 10 cm depth in the playa area during the wet season. All trophic group of nematodes were mainly distributed within the 0 – 10 cm, 10 – 20 cm and 20 – 30 cm in the loessial plain area during the dry season, and correlated positively with soil organic matter content and negatively with soil moisture and electrical conductivity. However, the trophic group of nematodes was mainly distributed within the 0 – 10 cm and 10 – 20 cm in the loessial plain area during the wet season, and positively correlated with soil organic matter content, soil moisture and electrical conductivity.

Nematode taxa

Total of 55 genera were observed, including 19 bacterivores, 10 fungivores, 12 plant-parasites, and 14 omnivore-predators (Table 4). Total of thirteen genera (including 6 bacterivores, 1 fungivores, 5 plant-parasites, and 1 omnivore-predators) were found in the playa area, while total of fifty-five genera (including 19 bacterivores, 10 fungivores, 12 plant-parasites, and 14 omnivore-predators) were found in the loessial plain area. *Acrobeloides*, *Metateratocephalus* and *Acrobeles* were the dominant genera in the playa area and were mainly present to the 0 – 20 cm depth, while *Acrobeles*, *Metateratocephalus*, *Cephalobus*, *Aphelenchoides*, *Chiloplacus* and *Acrobeloides* were the dominant genera in the loessial plain area and were also mainly present to the 0 – 20 cm depth.

Nematode ecological indices

F/B values at every soil layer in the loessial plain area were higher compared with the playa area during the dry and wet seasons (Table 5). Significant difference in the F/B values was found between locations ($P < 0.01$), but no significant differences were observed between depths and between seasons (Table 2). F/B values significantly negatively correlated with soil moisture (Table 3).

NCR values at every soil layer in the playa area were higher contrasted with the loessial plain area during the dry and wet seasons (Table 5). Significant difference in the NCR values was found between locations ($P < 0.001$), but no significant differences were

Fig. 2. Vertical distribution of nematode trophic groups at five soil depths in the playa and loessial plain areas during the dry and wet seasons. A. bacterivores, B. fungivores, C. plant parasites, D. omnivores-predators. PD-playa area during the dry season; PW-playa area during the wet season; CD- loessial plain area during the dry season; CW- loessial plain area during the wet season.

observed between depths and between seasons (Table 2). NCR values significantly positively correlated with soil moisture and electrical conductivity (Table 3).

T values at every soil layer in the loessial plain area were higher compared with the playa area during the dry and wet seasons (Table 5). Significant sampling locations effect was found on the T values ($P < 0.0001$), but no significant differences were observed between depths and between seasons (Table 2). T values correlated significantly negatively with soil moisture, soil organic matter content and electrical conductivity (Table 3).

H' values at every soil layer in the loessial plain area were higher than that in the playa area during the dry and wet seasons (Table 5). Significant sampling locations and seasons effects were found on the H' values ($P < 0.0001$), but no significant difference in H' values was observed between depths (Table 2). H' values significantly negatively correlated with soil moisture, soil organic matter content and electrical conductivity (Table 3).

The λ values at every soil layer in the loessial plain area were lower compared with the playa area during the dry and wet seasons (Table 5). Significant sampling location effect was found on the λ values ($P < 0.0001$), but no significant differences in the λ values were observed between depths and between seasons. Significant interaction effect of locations and seasons ($P < 0.0001$) was observed in the λ values (Table 2). The λ values significantly positively correlated with soil moisture, soil organic matter content and electrical conductivity (Table 3).

SR values at every soil layer in the loessial plain area were higher contrasted with the playa area during the dry and wet seasons (Table 5). Significant sampling location effect was found on the SR values ($P < 0.0001$), but no significant differences in the SR values were observed between depths and between seasons. Significant interaction effect of locations and seasons ($P < 0.01$) was detected in the SR values (Table 2). SR values significantly negatively correlated with soil moisture, soil organic matter content and electrical

Table 4. Number of soil nematode (individuals per 100 g dry soils) across all soil layers in the playa and loessial plain areas during the dry and wet seasons.

Genus	c-p* values	Dry season		Wet season	
		playa	loessial plain	playa	loessial plain
Bacterivores**					
<i>Acrobeles</i>	2	0.8***	74.9	0.3	42.3
<i>Acrobeloides</i>	2	2.7	24.4	0.3	07.1
<i>Alaimus</i>	4	0.0	00.0	0.0	00.1
<i>Cephalobus</i>	2	0.5	32.3	0.0	15.5
<i>Cervidellus</i>	2	0.0	04.8	0.0	00.0
<i>Chambersiella</i>	2	0.0	02.6	0.0	00.5
<i>Chiloplacus</i>	2	0.0	23.9	0.1	14.4
<i>Diploscapter</i>	1	0.0	00.0	0.1	02.9
<i>Eucephalobus</i>	2	0.0	00.9	0.0	02.0
<i>Mesorhabditis</i>	1	0.0	03.1	0.0	00.0
<i>Metateratocephalus</i>	3	3.0	46.8	0.0	20.7
<i>Monhystera</i>	2	0.0	00.0	0.0	00.1
<i>Panagrobelus</i>	1	0.0	00.0	0.0	00.9
<i>Panagrolaimus</i>	1	0.0	01.6	0.0	00.5
<i>Plectus</i>	2	0.0	03.4	0.0	00.1
<i>Protorhabditis</i>	1	0.0	00.0	0.0	00.1
<i>Rhabditis</i>	1	0.0	01.9	0.0	00.4
<i>Tylocephalus</i>	2	0.0	00.0	0.0	01.0
<i>Wilsonema</i>	2	0.0	01.3	0.0	00.0
Fungivores					
<i>Aphelenchoides</i>	2	0.4	38.2	0.0	07.8
<i>Aphelenchus</i>	2	0.0	08.6	0.0	09.2
<i>Aprutides</i>	2	0.0	00.0	0.0	00.2
<i>Diphtherophora</i>	3	0.0	00.0	0.0	00.7
<i>Ditylenchus</i>	2	0.0	00.0	0.0	00.1
<i>Nothotylenchus</i>	2	0.0	01.4	0.0	00.5
<i>Panaphelenchus</i>	2	0.0	00.0	0.0	00.5
<i>Tylencholaimellus</i>	4	0.0	03.2	0.0	02.2
<i>Tylencholaimus</i>	4	0.0	02.5	0.0	00.7
<i>Belonolaimus</i>	3	0.0	00.0	0.0	00.9
Plant-parasites					
<i>Filenchus</i>	2	0.0	01.4	0.0	01.2
<i>Helicotylenchus</i>	3	0.4	01.1	0.0	00.0
<i>Hoplolaimus</i>	3	0.0	02.1	0.0	01.4
<i>Longidorus</i>	5	0.0	05.5	0.0	00.1
<i>Paratylenchus</i>	2	0.0	00.0	0.0	01.6
<i>Pratylenchus</i>	3	0.0	02.1	0.0	02.9
<i>Telotylenchus</i>	3	0.0	01.3	0.1	02.8

<i>Tetylemus</i>	3	0.0	01.6	0.1	02.2
<i>Tridorus</i>	4	0.0	00.0	0.0	00.2
<i>Tylenchorhynchus</i>	3	0.0	07.7	0.1	03.2
<i>Tylenchus</i>	2	0.1	00.6	0.2	00.4
<i>Xiphinema</i>	5	0.0	02.8	0.0	00.0
Omnivores-predators					
<i>Aporcelaimellus</i>	5	0.0	01.1	0.0	02.5
<i>Aporcelaimus</i>	5	0.1	12.8	0.0	04.4
<i>Clarkus</i>	4	0.0	00.5	0.0	00.0
<i>Discolaimium</i>	5	0.0	00.0	0.0	00.2
<i>Discolaimus</i>	5	0.0	03.2	0.0	06.6
<i>Dorylaimellus</i>	5	0.0	07.6	0.0	01.4
<i>Dorylaimoides</i>	4	0.0	00.7	0.0	00.0
<i>Dorylaimus</i>	4	0.0	03.0	0.0	00.0
<i>Eudorylaimus</i>	4	0.0	06.3	0.0	00.0
<i>Labronema</i>	4	0.0	03.7	0.0	03.8
<i>Mesodorylaimus</i>	5	0.0	05.4	0.0	00.0
<i>Mononchus</i>	4	0.0	00.9	0.0	00.0
<i>Nygolaimus</i>	5	0.0	00.0	0.0	00.8
<i>Thonus</i>	4	0.0	00.0	0.0	04.5

*c-p values, characterized by life history characteristics, are adapted from Bongers (1990).

**Trophic groups according to Yeates *et al.* (1993).

***Means from four replicates.

conductivity (Table 3).

MI values at every soil layer in the loessial plain area were higher compared with the playa area during the wet season (Table 5). Significant sampling locations effect was found on the MI values ($P < 0.0001$), but no significant differences in the MI values were observed between depths and between seasons. Significant interaction effects of locations and depths, locations and seasons ($P < 0.05$) were detected in the MI values (Table 2). MI values significantly negatively correlated with soil moisture, soil organic matter content and electrical conductivity (Table 3).

MMI values at every soil layer in the loessial plain area were higher contrasted with the playa area, except the 30 – 40 cm layer during the wet season (Table 5). Significant sampling location effect was found on the MMI values ($P < 0.01$), but no significant differences in the MMI values were observed between depths and between seasons (Table 2). MMI values significantly negatively correlated with soil moisture, soil organic matter content and electrical conductivity (Table 3).

EI values in every soil layer in the loessial plain area were higher compared with the playa area (except the 0 – 10 cm layer during the wet season) during the dry and the wet seasons (Table 5). Significant differences in the EI values were found between locations ($P < 0.01$) and between seasons ($P < 0.05$), but no significant difference was observed between depths (Table 2). EI values significantly negatively correlated with electrical conductivity (Table 3).

SI values in every soil layer in the loessial plain area were higher contrasted with the playa area (except for the 0 – 10 cm and 40 – 50 cm layers during the dry season) during the dry and wet seasons (Table 5). Significant difference in the SI values was found between locations ($P < 0.0001$), but no significant differences were observed between depths and between seasons (Table 2). Significant interaction effects of locations and depths ($P < 0.05$), locations and seasons ($P < 0.01$) were detected in the SI values. SI values significantly negatively correlated with soil moisture, soil organic matter content and electrical conductivity (Table 3).

Integrating all the data using RDA (Fig. 3) for each of the sampling sites and seasons and soil depths indicated a strong effect between the dry (Fig. 3 A, B) and wet periods (Fig. 3 C, D) of each treatment. The relatively higher values of soil moisture (SM) during the wet period were found to explain the significant difference between the sampling sites. In the playa area (Fig. 3A, B) the SM was found to move to deeper layers, whereas the SM in loessial plain area remained close to the upper soil layer (Fig. 3 C, D). Different behavior of SM between the two sites explain the importance of soil pedological characteristics. The second variable known to play an important role in basic food source availability is the OM whose behavior was found to remain stable in the upper soil layers in both cases. These main variables were found to have the greatest significant effect on the soil free living nematode community abundance, distribution and trophic groups (Fig. 3), where

Table 5. Nematode ecological indices in different sampling sites, depths and seasons.

Index	Sampling depths (cm)									
	0-10		10-20		20-30		30-40		40-50	
	Playa	Control	Playa	Control	Playa	Control	Playa	Control	Playa	Control
Dry season										
F/B*	0.25b**	0.35a	0.13a	0.20a	0.00b	0.19a	0.13a	0.18a	0.00b	0.30a
NCR	0.88a	0.74b	0.92a	0.84a	1.00a	0.85b	0.90a	0.86a	1.00a	0.80b
T	1.29b	2.20a	1.42b	2.37a	1.23b	2.28a	1.44b	2.25a	1.00b	2.50a
H'	0.92b	2.23a	0.78b	2.32a	0.71b	2.12a	0.95b	2.23a	0.49b	2.10a
λ	0.44a	0.14b	0.54a	0.13b	0.55a	0.16b	0.41a	0.14b	0.66a	0.14b
SR	0.78b	1.89a	0.77b	2.07a	0.61b	1.99a	0.88b	2.19a	0.46b	2.12a
MI	2.43a	2.25b	2.25b	2.81a	2.17b	2.83a	2.35b	2.86a	2.71a	2.58b
MMI	2.43a	2.35a	2.25b	2.85a	2.48b	2.90a	2.39b	2.86a	2.71a	2.66a
EI	8.25b	34.75a	8.33a	14.75a	0.00b	11.25a	10.50a	15.50a	0.00b	22.50a
SI	54.50a	41.00b	25.00b	70.00a	23.00b	71.25a	49.50b	73.75a	83.25a	62.25b
Wet season										
F/B	0.00b	0.28a	0.00b	0.38a	0.00b	0.19a	0.00b	0.19a	0.00b	0.37a
NCR	1.00a	0.82b	1.00a	0.73b	1.00a	0.84b	1.00a	0.85b	1.00a	0.78b
T	1.20b	2.08a	1.00b	2.92a	1.00b	2.49a	1.00b	1.98a	1.00b	2.33a
H'	0.45b	2.42a	0.00b	2.32a	0.00b	2.15a	0.00b	2.09a	0.00b	2.05a
λ	0.71a	0.20b	1.00a	0.11b	1.00a	0.17b	1.00a	0.15b	1.00a	0.12b
SR	0.44	1.91	0.00	2.39	0.00	2.16	0.00	2.48	0.00	2.88
MI	1.75b	2.42a	2.00b	2.95a	2.00b	2.84a	2.00b	2.40a	2.00b	2.39a
MMI	2.13b	2.47a	2.00b	2.93a	2.00b	2.85a	2.50a	2.46a	2.50a	2.53a
EI	40.00a	26.00b	0.00b	20.25a	0.00b	23.50a	0.00b	29.25a	0.00b	32.50a
SI	0.00b	55.00a	0.00b	76.75a	0.00b	74.75a	0.00b	55.25a	0.00b	51.75a

*Abbreviations as in Table 2. **Mean values from four replicates, different letters at each layer in a line denote significant differences as assessed by *t*-test ($P < 0.05$).

in the playa area the OM was found to have a great effect on TN compared with the loessial plain area. Redundancy analysis reflected that the nematode community mainly distributed in the upper soil layers (0 – 20 cm) under the playa and loessial plain area.

Discussion

The playa and loessial plain area (as control) are two main geomorphological units in the inter-sand dune area in the North-Western Negev desert (Kidron *et al.*, 2008). Soil moisture, organic matter content and electrical conductivity in the playa area were higher than in the loessial plain area, reflecting the pedological differences and their effect on the soil biota community (Pen-Mouratov *et al.*, 2011; Yu *et al.*, 2012). The playa area represents a flat bare soil surface, scattered within the interdunes, with roughly no vegeta-

tion (perennial, microbiotic crusts) cover and very few tubules and holes, reflecting a rigorous soil environment, compared with the loessial plain area which is covered by a thin microbiotic crust and a vegetation cover which moderates the harsh abiotic environment (Kidron, 2001). Although there had high soil moisture and organic matter content in the playa area, high salt content may harm to soil biological community (Liang and Steinberger, 2001; Shamir & Steinberger, 2007), as revealed that there has less biological community in the playa area compared with loessial plain area. Our results which total number of nematode at every soil layer in the playa area was significantly less than in the loessial plain area during the dry and wet season testified this truth. These results manifested the aboveground and belowground components in the terrestrial ecosystems could interact. Total number of nematode in the present study were higher than that (4 – 200 individuals per

Fig. 3. Redundancy analysis (RDA) of soil moisture (SM), soil organic content (OM), electrical conductivity (EC), total number of nematode (TN), bacterivores (BF), fungivores (FF), plant – parasite nematode (PP) and omnivore – predator nematode (OP) with reference to different soil depths in the playa and loessial plain area during the dry and wet seasons. I, II, III, IV, V denote 0 – 10 cm, 10 – 20 cm, 20 – 30 cm, 30 – 40 cm and 40 – 50 cm soil depths; A, playa area during the dry season; B, loessial plain area during the dry season; C, playa area during the wet season; D, loessial plain area during the wet season.

100 g dry soils) in the horqin sandy land, Northeast China (Jiang *et al.*, 2007), yet was similar to the result (0 – 675 individuals per 100 g dry soils) in the Tehuacán Desert, Mexico (Pen-Mouratov *et al.*, 2008b). Total number of nematode had the gradual decreasing trends with soil depths, which could reflect the stratification of their food resources. Zhang *et al.* (2010) also observed the similar trend in the stable sand dune system. Pen-Mouratov *et al.* (2008b) found that total number of nematode was the highest at 0 – 10 cm sampling soil layer in the Tehuacán Desert.

Bacterivores were the most dominant trophic group in this study, which was consistent with the findings of Rahman *et al.* (2009) and Zhang *et al.* (2009). Nevertheless, this differed from the result reported by Wall *et al.* (2002), who found that omnivores were the dominant trophic group followed by bacterivores in a sand dune coastal system at the Tay River. This reflected that the differences of soil environment and plant cover between terrestrial and coastal sand dunes. Plant parasites were the most abundant trophic group near plant soils in the Tehuacán Desert, Mexico (Pen-Mouratov *et*

al., 2008b). Plant parasitic nematodes were the most dominant trophic groups in the wheat field in North China Plain (Hu & Qi, 2013). Bacterivores and fungivores at every soil layer in the loessial plain area were higher than that in the playa area during the dry and wet seasons, which revealed that there had little microbial community in the playa area in contrast to the loessial plain area. In the present study plant-parasitic nematodes were the least trophic group, and Pen-Mouratov *et al.* (2011) also reported similar results. Omnivores-predators in the sandy biological crust area were higher than that in the playa area (Pen-Mouratov *et al.*, 2011), which supported our findings. All nematode trophic groups were significantly influenced by sampling sites and depths (Pen-Mouratov *et al.*, 2008b), as also supported our results.

Total 55 nematode genera were observed in all soil samples, which was higher than the taxa of nematode reported by Zhang *et al.* (2007; 2010) in terrestrial sand dune system of China. But it was lower than the taxa of nematode reported by Wall *et al.* (2002) in sand dune system at the mouth of the river Tay. *Acrobeles* was the predominant genus, which was similar to the result from Danish sand dunes (Bussau, 1990) and from horqin sandy land in China (Jiang *et al.*, 2007, Zhang *et al.*, 2010). Pen-Mouratov *et al.* (2008a) also reported the similar results, which found that *Acrobeles* was dominant genus in the Negev Desert, Israel. However, Wall *et al.* (2002) reported that *dorylaimids* was dominant taxa in the sand dune soils of river. *Dorylaimus* was the most abundant in the inter plant soil spaces in the Tehuacán Desert, Mexico (Pen-Mouratov *et al.*, 2008b). *Prodorylaimus* was the predominant genus in the rice-wheat cropping system of central China (Hu *et al.*, 2018).

Nematode ecological indices can be used to estimate soil nematode community structure and composition (Yeates & Bongers, 1999). Ecological indexes are known to be a useful tool for helping differentiate between sampling depths and sites effect. Jiang *et al.* (2007) found that different treatment significantly effected on the values of all ecological indices, whereas sampling depths had no effect on nematode ecological indices. Zhang *et al.* (2010) reported that significant depth effects were found in the values of H' , λ , SR. Similarly, Pen-Mouratov *et al.* (2008b) reported that values of F/B, T, H' , MI had significantly different between soil layers.

Fungivore/bacterivore ratio (F/B) in the loessial plain area was higher than that in the playa area, which manifested that there had much more fungi community in the loessial plain area. Mean value of F/B was higher in the wet season under the loessial plain area than in the dry season, which showed that there had much more fungi community in the wet season in contrast to the dry season. The results reported by Yu *et al.* (2012) supported this findings.

Nematode channel ratio (NCR) reflects the soil bacterial or fungi decomposition pathway in the soil detrital food webs (Ruess, 2003). NCR values in the playa area were higher compared with loessial plain area, which manifested that bacterial decomposition pathway was predominant in the playa area. NCR values significantly negatively correlated with soil moisture and electrical con-

ductivity in the Horqin Sandy Land of China (Zhang *et al.*, 2007), which was inconsistent with the present study.

Trophic diversity index (T) demonstrates the diversity of the functional groups within the nematode community. T affords greater weight to common taxa, and a higher index indicates greater diversity (Heip *et al.*, 1988). T value in the loessial plain area were higher compared with playa area, which revealed that there had greater trophic diversity in the loessial plain area. Pen-Mouratov *et al.* (2011) observed similar result from the upper soil layer (0 – 10 cm) in the Negev Desert.

Shannon index (H') affords more weight to rare species, and a high value indicates greater diversity and Simpson index (λ) gives more weight to common species (Liang *et al.*, 2002). There had higher H' values and lower λ values in the loessial plain area in contrast to playa area, as revealed greater diversity in the loessial plain area. H' values were higher at 0 – 10 and 10 – 20 cm soil layers compared with the other layers in the loessial plain area, which manifested that there had greater diversity at 0 – 10 and 10 – 20 cm soil layers. H' values were significantly influenced by sampling sites and depths (Pen-Mouratov *et al.*, 2008b), whereas H' values were significantly influenced only by sampling sites in the present study.

Similarly, species richness (SR) values in the loessial plain area were greater than that in the playa area, and also indicating that there had abundant species in the loessial plain area. Yu *et al.* (2012) found that cultivable microfungus communities inhabiting the playa were lower species diversity compared with the interdune area regardless of soil depths and sampling seasons, which supported our findings.

Maturity index (MI) is a measure based on the composition of the nematode community and can reflect the degree of stability of the soil ecosystem (Bongers, 1990). MI values in the loessial plain area were higher in the wet season than that in the playa area, indicating a relatively higher environmental stability compared with the playa area. MI values significantly negatively correlated with soil organic matter content and electrical conductivity, however, Jiang *et al.* (2007) reported that MI values significantly positively correlated with soil organic carbon content and electrical conductivity in an age sequence of *Caragana microphylla* plantations sandy land. Nematode maturity index is modified to include plant-parasitic nematodes (MMI) and thus better reflect ecosystem development (Yeates, 1994), which MMI values also indicated that there had stable environmental conditions in the loessial plain area compared with the playa area.

Enrichment index (EI) provides an indicator of resources available to the soil food web and the response of primary decomposers to those resources (Wang *et al.*, 2006). EI values in the loessial plain area were higher than that in the playa area except at 0 – 10 cm depth in the wet season, which manifested that there had more sufficiently available nutrient in the loessial plain area. Obvious interaction effect of site and depth on EI was found in the stable and active sand dunes of Horqin Sandy Land (Zhang *et al.*, 2010),

as was different from our findings.

Structure index (SI) reflects the degree of trophic linkage in soil food webs and is an indicator of greater trophic links. Higher SI value indicates a food web that is more structured or stable, with more persisters (*k*-strategist) genera present (Wang *et al.*, 2006; Briar *et al.*, 2007). Significant sampling sites and depths effects on SI were found in the stable sand dune (Zhang *et al.*, 2010), but only sampling sites effect on SI was observed in the present study. In conclusion, total number of soil free living nematodes, trophic groups and ecological indices used were a good tool for explaining soil habitat environment differences. Soil free-living nematodes inhabited mostly the upper soil layers (0 – 20 cm) and nematode abundance was gradually decreasing trend with soil depths increasing in the playa and loessial plain area during the dry and wet seasons. Sampling sites and depths significantly effected on nematode abundance and trophic groups, however, only sampling sites significantly effected on nematode ecological indexes. Moreover, each soil layers had a little nematode abundance and community diversity in a playa area in contrast to loessial plain area during the dry and wet seasons.

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Conflict of interest

Authors state no conflict of interest.

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