SOIL ECOLOGY LETTERS

SEL

RESEARCH ARTICLE
Volume 5 / Issue 3 / 220166 / 2023
https://doi.org/10.1007/s42832-022-0166-y

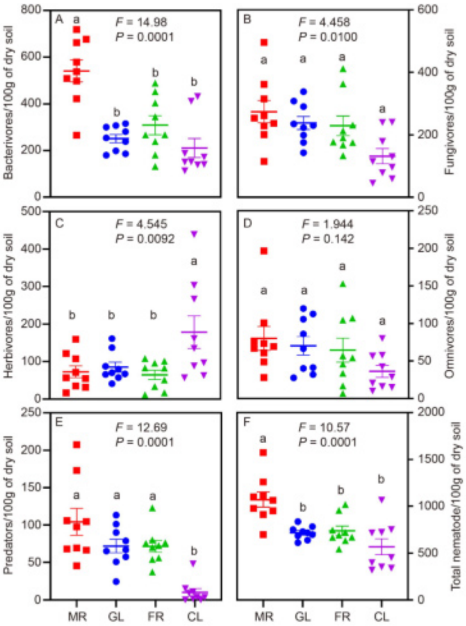
Impact of marshy area reclamation by various vegetations on soil-nematode community structure in Dachigam National Park

Humira Nesar*, Shahid Afzal, Zarrin Imran, Wasim Ahmad

Nematode Biodiversity Research Lab, Department of Zoology, Aligarh Muslim University, Aligarh 202002, India
* Corresponding author. E-mail: humiranesar09@gmail.com (H. Nesar)

Received September 11, 2022; Revised October 27, 2022; Accepted November 2, 2022

ABSTRACT



- Impact of marshy area reclamation by various vegetations on soil nematode community was investigated.
- Nematode abundance was lowered by reclamation mostly due to bacterivores.
- Reclamation effectively diminished the nematode metabolic footprint.
- Robust management strategies must be adapted for conservation and protection of marshy ecosystems.

Marshy areas are ecologically important and sensitive areas which are under immense pressure, such as reclamation by various terrestrial vegetations. However, how these vegetation types disrupt the stability of nematode community is scarce. The present study determined how the soil nematode community responded to shifting environmental states by using nematode abundances, nematode indices and metabolic footprints as indicators. In this context, we selected three types of reclaimed vegetation around a marshy land (MR) in Dachigam National Park, Kashmir, which includes grassland (GL), forest (FR) and cropland (CL) to investigate the soil nematode community. *Acrobeloides*, *Plectus*, *Eudorylaimus*, and *Aphelenchus* proved more sensitive to reclamation effect. Results revealed decrease in total nematode and bacterivore abundance. Reclamation reduced diversity in CL, whereas no effect was observed in the GL and FR as compared to MR. Channel index indicated shift from fungal decomposition to bacterial decomposition pathway in GL. The nematode faunal profile depicted grassland (GL) as the most structured ecosystem compared to MR, FR, and CL. Our results suggest that vegetation type regulates the structure, function, and stability of the soil food web, which has significant implications for managing the vegetation cover in a sustainable manner in the Dachigam National Park.

Keywords nematodes, diversity, vegetation, habitat, reclamation

1 Introduction

Sustainable land use issues have fascinated a lot of attention since the 1990s. Soil, as an significant component of sustainable ecosystems, is influenced by various land use regimes, which have varying effects on soil productivity and soil biota. Wetlands, which sequester carbon are one of the most important ecosystems in the response strategy against climate change (Verhoeven and Setter, 2010). However, their ability for carbon sequestration (CS) potential is currently declining due to human interference, with more reductions projected under scenarios involving global population expansion and climate change. As the wetlands reflect the borders between aquatic and terrestrial ecosystems, they are the most significant components of terrestrial environments and offer vital ecosystem services like flood prevention, water quality improvement, biological diversity preservation (Mitsch and Gosselink, 2007; Whitehouse et al., 2008), and carbon sequestration (Turner et al., 2000; Verhoeven and Setter, 2010). However, various forms of human disturbance such as wetland renovation have a significant negative influence on soil faunal populations, and the detritus food web, particularly nematodes (Nico et al.,

---

Cite this: Soil Ecol. Lett., 2023, 5(3): 220166

2013; Zhu et al., 2016). Nematodes are one of the most diverse metazoan group in land ecosystems and found in large numbers among the various groups of soil organisms (van den Hoogen et al., 2019). They control microbial community turnover, contribute to various trophic positions of soil food web and have important role in ecosystem function. They are the important members of detritus food web, and their high turnover rates and their interactions with microflora allow them to control residue decomposition and nutrient release (Zhang et al., 2015; Yang et al., 2021; Wilschut and Geisen, 2021).

They hold a unique place in the soil fauna for number of reasons: 1) They encompass most feeding groups in the soil food web including detritivores, plant-feeding and predators (Yeates et al., 1993; Ferris, 2010a), making them principally well-suited to study the impact of global climate change on various trophic positions within a particular faunistic group. 2) They quickly react to micro environmental changes (Ferris and Matute, 2003), and offer insightful information regarding compositional assembly and functional alterations in food web of soil, which can be helpful to evaluate soil health and functioning of ecosystem, especially in ecosystem restoration (Neher, 2001; Ferris and Matute, 2003). 3) Herbivore nematodes are well-known pests of agricultural crops (Evans et al., 1993), thus understanding their response in various land-use and climatic conditions is crucial for growers. Although nematodes are relatively unaffected by environmental warming (Yeates et al., 2002; De Long et al., 2016), diverse land-uses have an impact on nematode feeding types and community assembly of nematodes (Postma-Blaauw et al., 2010; Tsiafouli et al., 2015). Because nematodes have such a diverse life strategies and feeding forms, different functional guilds respond to environmental disturbances and global change in very different ways: while opportunistic nematodes, such as typical r-selected or colonizers, may profit from enhanced growth of plants and increased nutrient availability, the more sensitive k-selected or persister nematode groups may wane, causing in shortened and less complex food webs in soil (Ferris et al., 2001). These alterations can be estimated by functional indices derived from nematodes which may be used to draw broad assumptions regarding the ecosystem status (Bongers, 1990). Additionally, metabolic footprints can be used to quantify the influence of nematode functional guilds to environmental services (Ferris, 2010b). Nematodes perform a range of environmental services based on the condition food web in soil (Ferris, 2010b). Changes in land-use have an impact on soil faunal biodiversity and ecological services (Bender et al. 2016; Siebert et al., 2020). Agricultural management approaches alter nematode density, functional groups, and metabolic footprints, affecting ecosystem services provided by nematodes (Zhang et al., 2017). Agricultural intensification has revealed alterations in the food web complexity and biodiversity of soil due to drop in functional groups of nematodes (Tsiafouli et al., 2015).

Wetlands are productive and biologically varied environments. They provide a wide range of socioeconomic and ecosystem services, including as nutrient removal, environmental restoration, water purification, flood control, preservation and conservation of biodiversity, and habitat for wildlife (Dar et al., 2020). They provide supply of natural goods like fish, veggies, fodder, tourism, and a range of commercially significant aquatic plants (Bano et al., 2018). However, the area of lakes and wetlands have decreased dramatically in recent decades due to encroachment and land use changes. The future of lakes, marshes, and marshy places therefore seems to be in threat that would not only have an effect on society's socioeconomic situation but also make people more susceptible to calamities. Wetlands in Kashmir continue to deteriorate despite the rules and presence of wetland management officials (Dar et al., 2020). In this context, the marshy area of Dachigam National Park has undergone significant changes in recent years with reclamation by forest, grassland and cropland. Keeping this in consideration, a study was conducted to examine the effect of reclamation of marshy area by grassland, forest, and cropland on the soil nematode community.

The objective of this study was to determine the responses of soil nematode abundance, diversity, community structure and nematode metabolic footprints to reclamation. Considering this, we proposed the following hypothesis:

1) Reclamation of marshy area with forest, grassland and cropland will modify the environment that will harbor reduced abundances and diversity of nematodes as compared to marshy area. As marshy areas are considered carbon sinks (Turner et al., 2000; Dar et al., 2020) and conservation of biodiversity (Mitsch and Gosselink, 2007; Whitehouse et al., 2008), thus we predicted more nematode abundance and diversity in marshy area considering the response of nematodes to food sources which is primarily carbon driven.

2) Nematode community metabolic footprint will decrease in grassland, cropland and forest as we predicted marshy ecosystems being carbon sink areas channeled in nematodes.

2 Material and methods

2.1 Study area

The study area is situated in Dachigam National Park, 22 km from Srinagar, Jammu and Kashmir, which lies on the coordinates of 34°8′50″ N and 75°55′6.19″ E along the Zanskar mountain range of North-west Himalayan biogeographic region (Rodgers et al., 2000). It is about rectangular in shape, measuring 22.5 km long and 8 km wide comprising about half of Dal Lake's catchment area (Holloway and Wani 1970). It is surrounded by Sindh Valley to the north-east, Tarsar, Lidderwath, Kolhai of Lidder Valley, and Overa Aru Wildlife Sanctuary to the far east, Tral Range to the south-east, and Harwan, Brain, and Nishat to the west and south-west (Bhat et al., 2002). The area receives 546 mm of rainfall on average per year, with 32 mm being the minimum (Bhat, 1985). Apart from two dry spells that occur between April and June and, September and November, its climate is mainly sub-Mediterranean in nature (Singh and Kachroo, 1978). The park serves as an important example of the world's natural heritage for its tremendous biodiversity as well as diversity of endemic and endangered species, especially the Hangul (*Cervus elaphus hanglu*). Dachigam has a wide diversity of natural environments and is packed with different types of flora and fauna. For the current study, four sampling areas were chosen, each designating a different vegetation of the park.

Marshy area: situated in the west slope covering an area of 745.22 ha (Naqash and Sharma, 2011) which is continuously shrinking. The dominant vegetation is *Typha* sp.

Grassland: located in the south-facing slope of Dachigam, and the dominant vegetation is *Themeda anathera.*

Forest area: located along the north-facing slope of Dachigam. *Pinus wallichiana* is the dominant vegetation.

Cropland: located along the west slope of Dachigam. The dominant vegetation included paddy and maize.

2.2 Soil sampling

For each land-use type, three plots were selected randomly (15 m × 15 m for each) and within each plot three sub-plots (1 m × 1 m each) were set as sample replicates, separated by a minimal distance of 100 m. Five sub-samples, taken from the corners and center of each sub-plot, were combined to form a single composite soil sample. Removing the surface litter layer, a total of 36 samples of soil at 0–20 cm depth (3 plots × 3 sub-plots × 4 land-use types) were taken with the help of small trowel in September 2019. To prevent desiccation, these soil samples were kept in air tight plastic bags and delivered to the laboratory within 4 days. The samples were processed within two weeks and kept at 4°C in a refrigerator until further analysis.

2.3 Soil properties

pH of soil was estimated by making a 20 g of soil suspension in 50 mL of deionized water using pH meter (ECPHTUTOR). Soil moisture (SM) determined gravimetrically by drying the fresh sample at 40°C for seven days and soil organic matter (SOM) was estimated by loss on ignition method as described by Davies (1974). Soil properties are presented in Table S1.

2.4 Nematode extraction

Nematodes were extracted from 100 g of soil by Cobb's decanting and sieving method (Van Bezooijen, 2006). Each soil sample was mixed with water in 1 L beaker. The suspension was stirred using wooden paddle followed by decantation passing through a 2 mm mesh sieve to separate out large debris. The suspension was further stirred and decanted through 53-μm pore size sieve. The left over material on sieves was taken in a 100 mL beaker. This material was transferred to individual sieves covered with double layer of tissue paper and placed on individual funnels and, further processed by Baerman's funnel technique.

2.5 Nematode identification and characteristics of nematode communities

Samples were collected after extraction for 2 days, stored at room temperature. The aqueous suspension was observed under an inverted microscope (Olympus SZX10) under which excess water was removed with the help of hypodermal needle. Fixation of nematodes was done with TAF and counted using Syracuse dish under inverted microscope. Furthermore, 200 nematodes from each sample were identified to generic level using Olympus BX41 microscope, with the help of various texts (Goodey, 1963; Jairajpuri and Ahmad, 1992; Ahmad, 1996; Andrássy, 2005; Ahmad and Jairajpuri, 2010). The genera identified were allocated to different functional guilds with the help of feeding habit and C-P value (Bongers and Bongers, 1998; Ferris et al., 2001).

Diversity of nematodes were assessed using PAST 3.26 and various indices were calculated which include, Simpson's index of diversity (*1-D*), Shannon–Weiner index ($H' = \Sigma\ Pi\ (\ln Pi)$), Eveness index ($J' = H'/\ln S$) and Chao 1 index (*GR*), where $Pi = n/N$, *n* represents number of individuals of a particular genus in a sample, *N* is total number of individuals in a sample, *S* is total number of genera in a sample. With the help of functional guilds six functional indices were calculated to assess the status of soil ecosystems using nematode communities which include: (1) maturity index, (2) maturity index 2-5, (3) Sigma Maturity index ($\Sigma\ MI = \Sigma\ \mathrm{v}\ (\mathrm{i}) \times \mathrm{f}\ (\mathrm{i})/n$); these indices quantify the degree of disturbance in soil ecosystem with lower values representing more disturbance, *MI* takes into consideration free living nematodes of all five cp values and *MI*2-5 takes into consideration all free-living excluding cp1 and SMI includes all the nematode including cp1 and plant-parasites, (4) Plant parasite index ($PI = \Sigma\ \mathrm{v}\ (\mathrm{i}) \times \mathrm{f}\ (\mathrm{i})/n$) (Bongers,1990), (5) Basal index ($BI = 100 \times \mathrm{b}/\ \mathrm{b} + \mathrm{e} + \mathrm{s}$), (6) Channel index ($CI = 100 \times (\mathrm{W2\ Fu2/W1Ba2 + Fu2})$) (Ferris et al., 2001). Metabolic footprints of the nematode community were calculated using the following equations:

1) $W = (D2 \times L)/(1.6 \times 106)$, (Andrássy, 1956)

2) $F = \Sigma\ (Nt\ (0.1\ (Wt/mt) + 0.273\ (Wt0.75)))$, (Ferris, 2010b)

where W, D and L denote nematode biomass (µg), body diameter (µm) and body length (µm) respectively, Nt is the nematode abundance in genus t, Wt is biomass of genus t, and mt is the c-p value of the genus t. All functional indices and metabolic footprints were calculated by NINJA online program (Sieriebriennikov et al., 2014).

2.6 Analysis of data

Variations in total nematode abundance, trophic abundance, diversity, functional indices and metabolic footprint was analyzed by one way ANOVAs followed by post-hoc Duncan's test using SPSS20 software (SPSS Inc., Chicago, IL). To visualize the distribution pattern of nematode communities, multivariate analysis NMDS based on Bay-Curtis similarity measure was plotted using one-way analysis of similarity (ANOSIM) with the help of software PAST 3.26 (Hammer, 2001). Principal component analysis (PCA) was used to analyze the correlation between nematode genera abundance and soil properties as well as the preference habitat for specific nematode genera using software Origin-Pro 2021.

3 Results

3.1 Soil properties

Reclamation of marshy area with grassland, forest and cropland significantly decreased pH, SOM and SM.

3.2 Taxonomic composition of nematodes

A total of 27 861 nematode individuals were recorded, representing 69 genera from 36 soil samples, collected from four habitats (Table S2). 54 genera were found in marshy area, 41 in grassland, 50 in forest and 38 in cropland. Out of 69 genera, bacterivores represented by 20 genera were the most dominant followed by fungivores (17 genera), herbivores (15 genera), predators (11 genera) and omnivors (6 genera). In marshy area, Ba were dominant (51.22%) followed by Fu (24.89%), Pr (9.78%) and, He and Om (7.05%). In grassland, Ba were dominant (35.44%) followed by Fu (33.27%), He (11.77%), Pr (10%) and Om (9.5%). In forest, Ba were dominant (41.61%) followed by Fu (30.33%), Pr (10.11%), He (9.22%) and Om (8.72%). In cropland, Ba were dominant (37.65%) followed by He (29.75%), Fu (24.31%), Om (6.68%) and Pr (1.62%). In all the four habitats, bacterivores were most abundant trophic group. 4 genera (*Pelodera, Enchodelus, Iotonchus* and *Longidorus*) were found only in marshy area; 1 genus (*Rotylenchus*) was found only in grassland; 2 genera (*Diptherophora* and *Moshajia*) were found only in forest, and 8 genera (*Chiloplacus, Wilsonema, Paraoxydirus, Labronema, Epidorylaimus, Pratylenchus, Hirschmaniella* and *Trichodorus*) were found only in cropland.

3.3 Trophic abundance

The marshy area reclamation by GL, FR and CL significantly decreased the bacterivore and total nematode abundance (Fig. 1A, F). The abundances of Fu and Pr remained unaffected by conversion of MR into GL and FR, whereas, in CL a significant decrease was found (Fig. 1B, E). In contrast, just opposite was found for He (Fig. 1C). Non-significant ($p > 0.05$) effect of reclamation of marshy area by GL and FR was found and significant decrease was found in CL for omnivore nematodes (Fig. 1D). The nematode community composition based on abundance and presence-absence of genera was different among the vegetation types shown by separate clusters formed by samples in NMDS (Global R = 0.18, $p < 0.01$) (Fig. 2).

3.4 Nematode indices and food-web analysis

The diversity indices of the nematode assemblages are shown in Table 1. Shannon index (H') and Generic richness (GR) were found significantly higher in MR and FR in comparison to GL and CL. The values of Simpson index (1-D) and Evenness (J') were found significantly greater in GL, MR and FR in comparison to CL and the values of Evenness remained unaffected.

The nematode maturity indices (MI, MI2-5 and SMI) exhibited a similar pattern, following the order of GL > MR = FR > CL (Table 1). The values of Plant Parasitic Index (PPI) were unaffected by vegetation type (Table 1). CI values was found significantly higher in GL in comparison to MR, FR and CL (Table 1), in contrast BI was higher in CL as compared to other vegetations (Table 1). Nematode fauna with the help of EI and SI is divided into four quadrats. In our study, most of the samples of MR, FR and CL, and GL separated in quadrat B and C respectively characterizing the soil environment as maturing, fertile with low to moderate damage and structured, undisturbed with balanced supply of nutrients respectively (Fig. 3).

3.5 Nematode metabolic footprint

The metabolic foot print of nematode community varied considerably under vegetation types (Fig. 4). Reclamation decreased the composite metabolic footprint was as higher value was recorded in MR. Enrichment footprint was higher in MR and lower in GL. Structure footprint was greater in MR

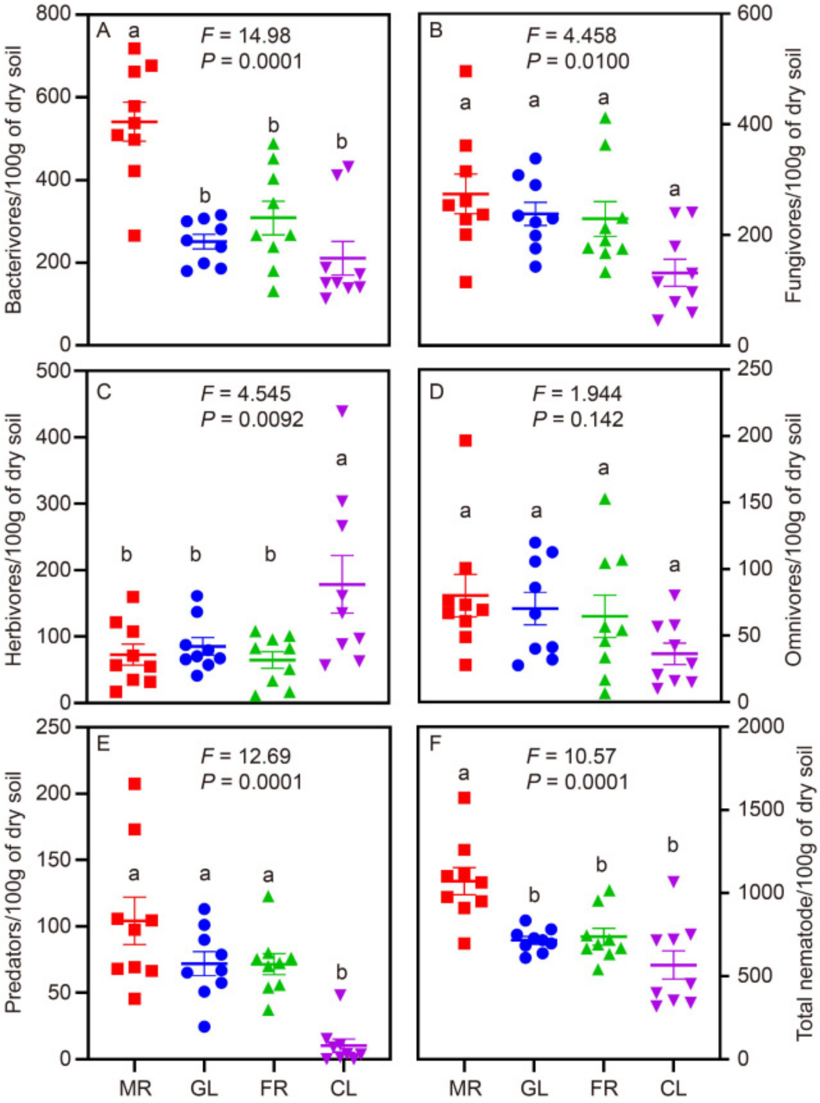


Fig. 1 Total nematode abundance in four vegetation types (mean ± SE, n = 9). Different small case letters in each row of every graph indicated significant difference between vegetation types.

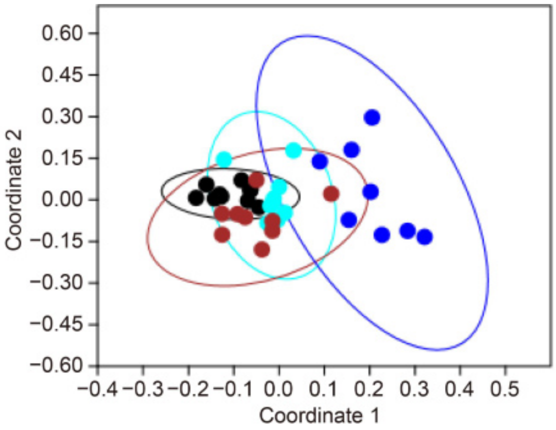


Fig. 2 NMDS of nematode community structure using Bray-curtis similarity measure on abundance and presence-absence of nematode genera in relation to four vegetation types where square, triangle, diamond and inverted triangle represent samples from MR, GL, FR and CL respectively. Circles represent 95% confidence interval.

and lesser in CL. Herbivore footprint was higher under CL in comparison to other vegetations. Fungivore footprint was greater in MR, GL and FR, and lower in CL. Bacterivore footprint significantly followed the order of MR > CL = FR > GL. Predatory footprint significantly decrease in CL while as Omnivore footprint was found same in all the four vegetations. Reclamation decreased the functional metabolic footprint as more area was occupied by MR compared to other vegetation types (Fig. 5).

3.6 Relation of soil nematode genera with abiotic factors

Principal component analysis (PCA) was performed based on entire nematode generic composition from MR, GL, FR and CL and soil abiotic factors (Fig. 6). Genera scatter plot and ordination of soil samples on bi-plot resulting from the PCA showed 11.78% variability by first axis and 9.14%

Table 1 Various ecological indices of soil nematode community under various vegetation types.

Indices	MR	GL	FR	CL	*F*-value	*P*-value
Shannon index (*H′*)	2.91±0.03a	2.72±0.04b	2.90±0.03a	2.56±0.07b	11.43	0.0001
Simpson index (*1-D*)	0.93±0.01a	0.92±0.01a	0.93±0.01a	0.89±0.01b	10.59	0.0001
Eveness (*J′*)	0.79±0.01a	0.82±0.02a	0.82±0.02a	0.73±0.03b	3.515	0.0261
Generic richness (*GR*)	23.55±0.80a	18.88±0.90b	22.55±1.13a	17.88±0.84b	8.809	0.0002
MI	2.48±0.09b	3.11±0.07a	2.66±0.11b	2.39±0.06c	13.25	0.0001
*MI*2-5	2.89±0.06b	3.21±0.07a	3.08±0.07b	2.57±0.07c	15.64	0.0001
SMI	2.49±0.09b	3.08±0.06a	2.67±0.10b	2.48±0.10c	8.387	0.0003
PPI	2.64±0.13a	2.72±0.17a	2.73±0.11a	2.7±0.22a	0.2002	0.8955
CI	21.98±6.85b	49.54±10.27a	17.09±2.43b	41.28±11.32ab	3.327	0.0317
BI	14.42±0.90b	14.17±1.71b	11.50±0.77b	26.68±3.22a	12.5	0.0001

Values are mean ± SE (n=9). Different small case letters in a row indicate significant difference between means according to Duncan's post hoc test at $p \leqslant 0.05$.

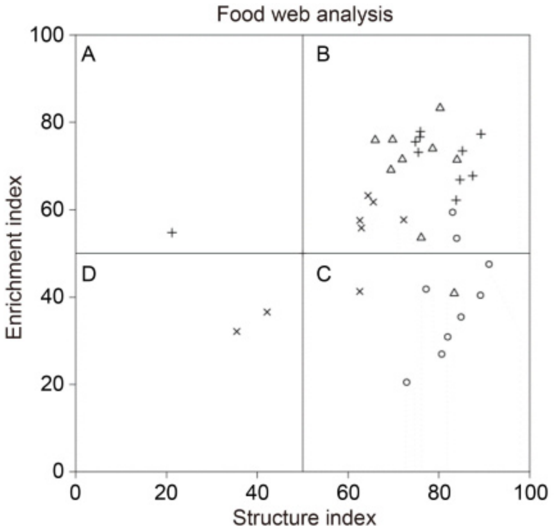


Fig. 3 Soil nematode food web structure under four vegetation types. (triangle, circle, plus and cross represent MR, GL, FR and CL respectively). The enrichment index and structure index are defined by the vertical and horizontal axes, respectively (n = 9).

variability by the second axis. From PCA it can be seen that MR was clearly divergent in generic composition than that of other three reclaimed vegetations. Results showed that genera like *Acrobeloides, Metadiplogaster, Plectus, Dorylaimellus, Prismatolaimus, Eudorylaimus, Doryllium, Rotylenchus, Aporcelaimellus* and *Coslenchus* showed positive correlation with pH, SOM and SM. *Acrobeles, Tylenchus, Helicotylenchus* were negatively correlated with pH, SOM and SM.

4 Discussion

Here we emphasized at how an ecologically significant group of soil nematodes responded to the reclamation of marshy areas with grassland, forest, and cropland in order to get a clear sense of their structural and functional shift as a result of the change in vegetation type. Our results showed that complex changes in soil nematode communities were particularly caused by aboveground vegetation change. Marshy area reclamation by different vegetation, changed the soil nematode community significantly. In general, nematode assemblages and their derived ecological functions reflected the differences between marshy area and its reclamation by different vegetation which includes GL, FR and CL. Present study showed that displacement of marshy area by GL, FR and CL significantly decrease the abundance of total nematodes and bacterivores. This may be due to the destruction of the native habitat and sensitivity of the nematodes toward disturbance induced by reclamation that alters the natural attributes and biological resources over time which makes these changes irreversible to some extent. These findings are in line with our first hypothesis and various previous studies which stated that soils under native vegetation usually show higher nematode abundance (Cardoso et al., 2015; Vazquez et al., 2019). In addition to this, marshy area are considered rich sinks of CS (Verhoeven and Setter, 2010), thus we speculated that more carbon accumulation on the soil surface favor microbial activity (Li et al., 2015; Zhang et al., 2015) which in turn enhanced bacterial nematode density. Furthermore, across all vegetation- use types including marshy area bacterial feeding nematodes was dominant which is consistent with examining the functional diversity of nematodes across terrestrial environments (Sechi et al., 2018) and, global scale feeding group composition across diverse biomes (van den Hoogen et al., 2019). The abundance of trophic groups mainly fungivores and predators was effected by the reclamation of marshy area with cropland. However, no such effect was observed by reclamation of marshy area with FR and GL. This can be explained that fungivores tend to predominate

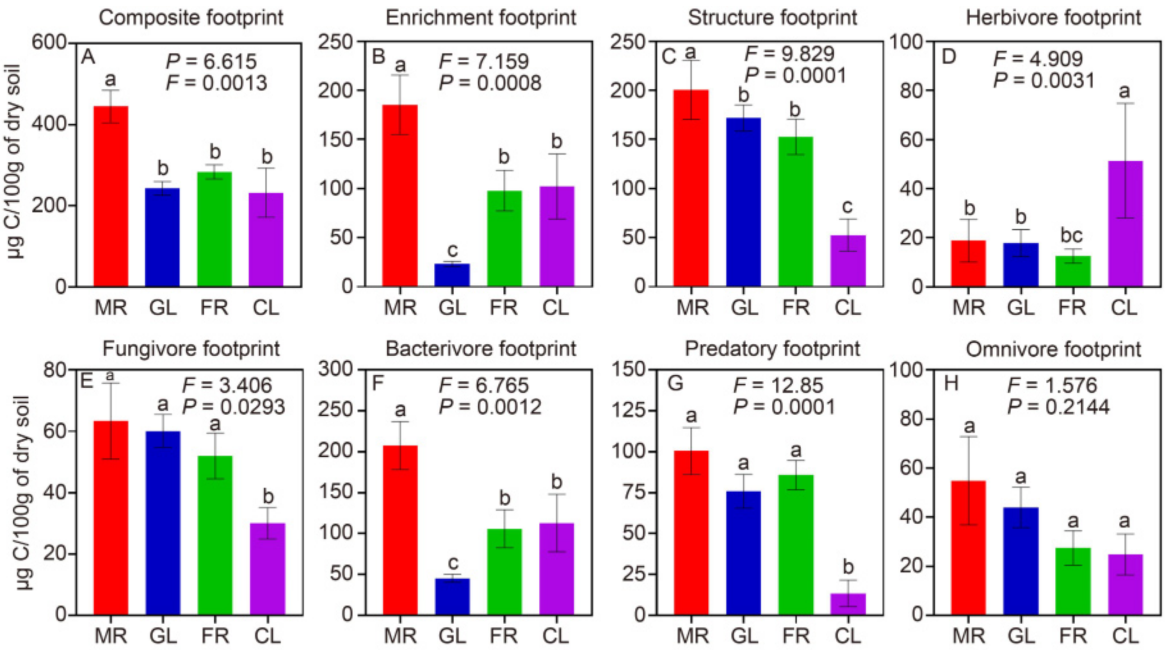


Fig. 4 Nematode metabolic footprint under different vegetation types (mean ± SE, *n* = 9). Different small case letters in each row of every graph indicated significant difference between vegetation types.

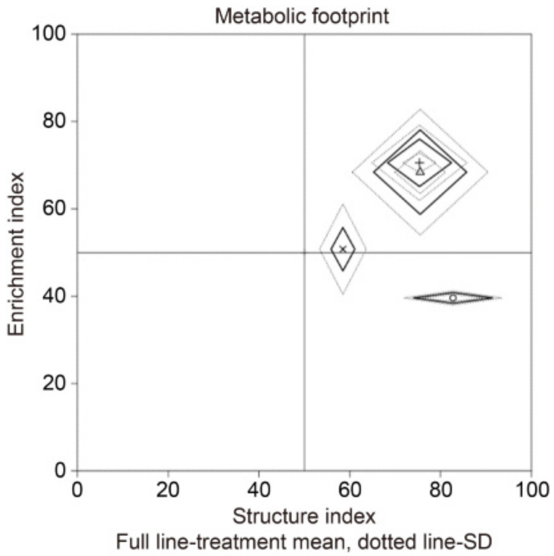


Fig. 5 Functional metabolic footprint of nematode under four different land uses (triangle, circle, plus and cross represent MR, GL, FR and CL respectively). The vertical axis and horizontal axis represent enrichment footprint and structure footprint of nematode community under four land uses (*n* = 9).

and increase in number in areas where complex material with high content of cellulose and lignin is present favoring slower fungal decomposition (Bongers and Bongers, 1998; Ferris et al., 2001). As for as omnivores and predators are concerned, they often disappear with cultivation as in our case in CL, as they are sensitive to soil disturbance which is confirmed by large body of previous literature (Bongers, 1990; Sanchez-Moreno et al., 2006; Zhao and Neher, 2013; Li et al., 2016). The data obtained in the present study indicated that marshy area reclamation by cropland increases the abundance of herbivore nematodes, however they were not affected by reclamation of MR with GL and FR. This increased abundance of herbivore nematodes in CL may be due to their specific parasitic behavior and increased plant biomass N content in plant tissues which shoot up their population (Reich et al., 2006; Duyck et al., 2012).

Nematode biodiversity as indicated by alpha diversity indices reflected the diversity of different habitats in present study, these indices were significantly higher in MR, FR and GL as compared to CL. It is in accordance with the general assumption that undisturbed ecosystems have more diverse soil fauna (Kandji et al., 2001; Vazquez et al., 2019) which is possibly due to larger heterogeneity of resources added through the return of residual matter and root-exudates (Ou et al., 2005). The decrease in diversity in CL suggested exploitation by various anthropogenic pressures in CL which could affect the biodiversity of soil nematodes. These results supported the findings that the diversity of nematodes is higher in undisturbed ecosystems than in human-disturbed ecosystems as in our case the cropland (Briar et al., 2007; Darby et al., 2007). These were congruent with the general statement that ecosystems with less or no disturbance support greater richness of soil biota (Hooper et al., 2005) consistent with the results of Quist et al. (2016) and Puissant et al. (2021). In our study GL had highest values of maturity indices, MR and FR had intermediate value of maturity indices and CL had lowest value of maturity indices. From this it can be concluded that GL are stable ecosystems, whereas, MR and FR had immediate disturbance and CL undisturbed ecosystems. Soil cultivation usually disturb the

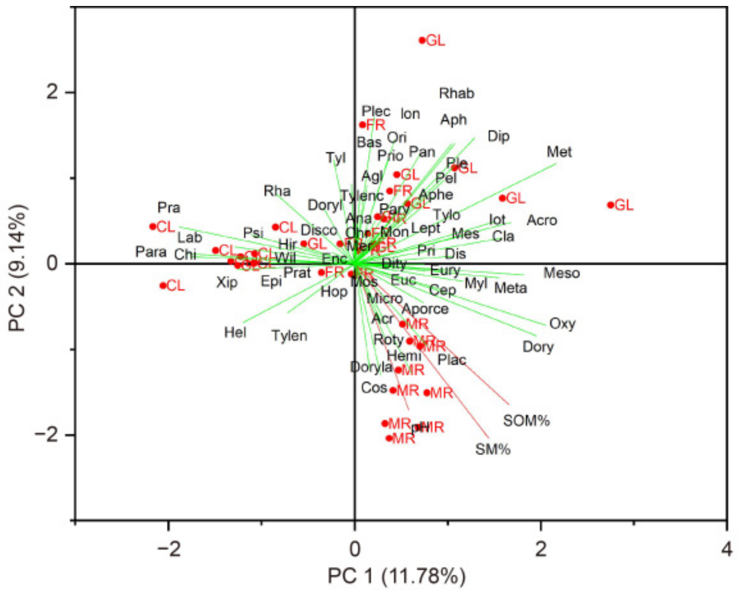


Fig. 6 Principal component analysis based on nematode genera composition in four vegetation types in MR, GL, FR and CL which depicted a variation of 11.78% and 9.14% by first and second axis respectively. Abbreviations of nematode genera are shown in Table S1.

ecosystem and this is evident from the low maturity indices for CL which is consistent with earlier studies (Asiedu et al., 2019; Hirschfeld et al., 2020). The plant parasitic index remained unaffected due to reclamation of marshy area with different vegetations. Channel index was found higher in GL as compared to other vegetations. The *CI* is defined as the indicator of decomposition pathway with higher *CI* values revealing fungal decomposition pathway, while lower values imply bacterial decomposition pathway. In our study, higher *CI* values were found in grassland and significantly lower in FR, MR and CL. This is in accordance with Bardgett et al., (1996). The Basal index (*BI*) measures the prevalence of functional guilds of nematodes that can tolerate perturbation. *BI* values were higher in CL reflecting greater disturbance, similar results were also reported in annual cropping (Culman et al., 2010). The EI and SI, which both describe the status of the food web, are based on the indicator significance of functional guilds of nematodes. The trajectories enable us to estimate soil food condition through EI (a measure of opportunistic bacterivore and fungivore nematodes) and the SI (determined by omnivore and predatory nematodes indicate the food web state affected by disturbance). In our study, faunal analysis depicted that samples from GL mostly fall in quadrant C indicating resource limited and structured habitat, whereas, samples from MR, FR and CL were mostly found in quadrant B indicating the enriched habitats with less disturbance. In our study, the reclamation of marshy area by GL, FR and CL decrease the composite metabolic footprint which indicates that nematodes sustain large proportion of carbon energy flow in the soil food web in marshy areas. However, replacement of marshy area with other land uses lowers the mitigation of carbon in the form of soil nematode metabolic footprint which is in accordance to our second hypothesis. The increase in herbivory footprint in cropland may be attributed to the specific crop and plant vigor which is possibly due to addition of fertilizers that resulted in higher abundance and carbon footprint of herbivorous nematodes (Wang et al., 2006).

5 Conclusion

Our results demonstrated that marshy area reclamation affected soil nematode community significantly. Marshy area is a critical ecosystem as well as biologically diverse region which offer valuable services as indicated in our study. Overall we found that nematode diversity, abundance and metabolic footprint decreases with the replacement of marshy area, which suggest that healthy management approaches must be adapted for safeguard and protection of marshy ecosystems. We also encourage to use nematode genera, functional guilds and functional indices of nematodes to track alterations in soil ecosystem settings produced by various perturbations to precisely understand the processes and status of soil ecosystems.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

We are thankful to the Department of Zoology, Aligarh Muslim

University for providing the required facilities to carry out this work. The first and second authors are thankful to the University Grants Commission (UGC), New Delhi and Council of Scientific and Industrial Research (CSIR) for providing the stipend.

Electronic supplementary material

Supplementary material is available in the online version of this article at https://doi.org/10.1007/s42832-022-0166-y and is accessible for authorized users.

References

Ahmad, W., 1996. Plant Parasitic Nematodes of India: An Identification Manual. Department of Zoology, Aligarh Muslim University, p. 347.

Ahmad, W., Jairajpuri, M.S., 2010. Mononchida: The Predaceous Nematodes. In: Brill, E.J., ed. Nematology Monographs and Perspectives 7. Leiden, The Netherlands pp. 299.

Andrássy, I., 1956. The determination of volume and weight of nematodes. Acta Zoologica Academiae Scientiarum Hungaricae 2, 1–15.

Andrássy, I., 2005. Free-living nematodes of Hungary: Nematoda Errantia (Vol. 1). Budapest, Hungary: Hungarian Natural History Museum.

Asiedu, O., Kwoseh, C.K., Melakeberhan, H., Adjei-Gyapong, T., 2019. Nematode distribution in cultivated and undisturbed soils of Guinea Savannah and Semi-deciduous Forest zones of Ghana. Geoscience Frontiers 10, 381–387.

Bano, H., Lone, F.A., Bhat, J.I.A., Rather, R.A., Malik, S., Bhat, M.A., 2018. Hokersar Wet Land of Kashmir: its utility and factors responsible for its degradation. Plant Archives 18, 1905–1910.

Bardgett, R.D., Hobbs, P.J., Frostegård, A., 1996. Changes in soil fungal: bacterial biomass ratios following reductions in the intensity of management of an upland grassland. Biology and Fertility of Soils 22, 261–264.

Bender, S.F., Wagg, C., van der Heijden, M.G., 2016. An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability. Trends in Ecology & Evolution 31, 440–452.

Bhat, G.A., 1985. Biological studies of Grassland of Dachigam National Park, Kashmir. Ph.D. thesis, CORD, University of Kashmir, Srinagar., 521p.

Bhat, G. A., Qadri, M. Y., Zutshi, D. P., 2002. An ecological survey of Dachigam National Park, Kashmir with emphasis on grasslands. Natural Resources of Western Himalaya,, 341–376.

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

Bongers, T., Bongers, M., 1998. Functional diversity of nematodes. Applied Soil Ecology 10, 239–251.

Briar, S.S., Jagdale, G.B., Cheng, Z., Hoy, C.W., Miller, S.A., Grewal, P.S., 2007. Indicative value of soil nematode food web indices and trophic group abundance in differentiating habitats with a gradient of anthropogenic impact. Environmental Bioindicators 2, 146–160.

Cardoso, M.D.O., Pedrosa, E.M.R., Ferris, H., Rolim, M.M., Vicente, T.D.S., David, M.D.L., 2015. Comparing sugarcane fields and forest fragments: the effect of disturbance on soil physical properties and nematode assemblages. Soil Use and Management 31, 397–407.

Culman, S.W., DuPont, S.T., Glover, J.D., Buckley, D.H., Fick, G.W., Ferris, H., Crews, T.E., 2010. Long-term impacts of high-input annual cropping and unfertilized perennial grass production on soil properties and belowground food webs in Kansas, USA. Agriculture, Ecosystems & Environment 137, 13–24.

Dar, S.A., Bhat, S.U., Rashid, I., Dar, S.A., 2020. Current status of wetlands in Srinagar City: threats, management strategies, and future perspectives. Frontiers in Environmental Science 7, 199.

Darby, B.J., Neher, D.A., Belnap, J., 2007. Soil nematode communities are ecologically more mature beneath late-than early-successional stage biological soil crusts. Applied Soil Ecology 35, 203–212.

Davies, B. E., 1974. Loss-on-ignition as an estimate of soil organic matter. Soil Science Society of America Journal 38, 150–151.

De Long, J.R., Dorrepaal, E., Kardol, P., Nilsson, M.C., Teuber, L. M., Wardle, D.A., 2016. Contrasting responses of soil microbial and nematode communities to warming and plant functional group removal across a post-fire boreal forest successional gradient. Ecosystems (New York, N.Y.) 19, 339–355.

Duyck, P., Dortel, E., Tixier, P., Vinatier, F., Loubana, P.M., Chabrier, C., Quénéhervé, P., 2012. Niche partitioning based on soil type and climate at the landscape scale in a community of plant-feeding nematodes. Soil Biology & Biochemistry 44, 49–55.

Eisenhauer, N., Dobies, T., Cesarz, S., Hobbie, S.E., Meyer, R.J., Worm, K., Reich, P.B., 2013. Plant diversity effects on soil food webs are stronger than those of elevated CO_2 and N deposition in a long-term grassland experiment. Proceedings of the National Academy of Sciences of the United States of America 110, 6889–6894.

Evans, K., Trudgill, D.L., Webster, J.M., 1993. Plant-Parasitic Nematodes in Temperate Agriculture. Wallingford, UK: CAB International.

Ferris, H., 2010a. Contribution of nematodes to the structure and function of the soil food web. Journal of Nematology 42, 63–67.

Ferris, H., 2010b. Form and function: metabolic footprints of nematodes in the soil food web. European Journal of Soil Biology 46, 97–104.

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

Ferris, H., Matute, M.M., 2003. Structural and functional succession in the nematode fauna of a soil food web. Applied Soil Ecology 23, 93–110.

Goodey, T., 1963. Soil and Freshwater Nematodes. New York: John Wiley and Sons.

Hammer, Ø., Harper, D. A., & Ryan, P. D., 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontol. Electron 4, 9.

Hirschfeld, M.N.C., Cares, J.E., Esteves, A.M., 2020. Land use, soil properties and climate variables influence the nematode communities in the Caatinga dry forest. Applied Soil Ecology 150, 103474.

Holloway, C.W., Wani, A.R., 1970. Management plan for Dachigam Sanctuary, 1971-1975. Cyclostyled. pp. 26.

Hooper, D. J., Hallmann, J., Subbotin, S. A., 2005. Methods for extraction, processing and detection of plant and soil nematodes. In: Luc, M., Sikora, R.A., Bridge, J., eds. Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. Wallingford UK: CABI Publishing. pp. 53−86.

Jairajpuri, M.S., Ahmad, W., 1992. Dorylaimida: Free Living, Predaceous and Plant Parasitic Nematodes. Leiden, The Netherlands and Oxford & IBH, New Delhi, p. 458.

Jiang, Y., Liu, M., Zhang, J., Chen, Y., Chen, X., Chen, L., Sun, B., 2017. Nematode grazing promotes bacterial community dynamics in soil at the aggregate level. ISME Journal 11, 2705–2717.

Kandji, S.T., Ogol, C.K., Albrecht, A., 2001. Diversity of plant-parasitic nematodes and their relationships with some soil physico-chemical characteristics in improved fallows in western Kenya. Applied Soil Ecology 18, 143–157.

Li, J., Zou, C., Xu, J., Ji, X., Niu, X., Yang, J., Zhang, K.Q., 2015. Molecular mechanisms of nematode-nematophagous microbe interactions: basis for biological control of plant-parasitic nematodes. Annual Review of Phytopathology 53, 67–95.

Li, X., Lewis, E. E., Liu, Q., Li, H., Bai, C., & Wang, Y., 2016. Effects of long-term continuous cropping on soil nematode community and soil condition associated with replant problem in strawberry habitat. Scientific Reports 6, 1–12.

Liu, T., Chen, X., Hu, F., Ran, W., Shen, Q., Li, H., Whalen, J.K., 2016. Carbon-rich organic fertilizers to increase soil biodiversity: Evidence from a meta-analysis of nematode communities. Agriculture, Ecosystems & Environment 232, 199–207.

Mitsch, W.J., Gosselink, J.G., 2007. Wetlands, 4th edition; New York: John Wiley & Sons, p. 581.

Naqash, R.Y., Sharma, L., 2011. Management plan for Dachigam National Park (2011-2016). Jammu & Kashmir: Srinagar, p. 172.

Neher, D.A., 2001. Role of nematodes in soil health and their use as indicators. Journal of Nematology 33, 161.

Nico E, Tomasz D, Simone C et al., 2013. Plant diversity effects on soil food webs are stronger than those of elevated CO_2 and N deposition in a long-term grassland experiment. Proceedings of the National Academy of Sciences, 110, 6689–6694.

Ou, W., Liang, W., Jiang, Y., Li, Q., Wen, D., 2005. Vertical distribution of soil nematodes under different land use types in an aquic brown soil. Pedobiologia 49, 139–148.

Postma-Blaauw, M.B., de Goede, R.G.M., Bloem, J., Faber, J.H., Brussaard, L., 2010. Soil biota community structure and abundance under agricultural intensification and extensification. Ecology 91, 460–473.

Puissant, J., Villenave, C., Chauvin, C., Plassard, C., Blanchart, E., Trap, J., 2021. Quantification of the global impact of agricultural practices on soil nematodes: A meta-analysis. Soil Biology & Biochemistry 161, 108383.

Quist, C.W., Schrama, M., de Haan, J.J., Smant, G., Bakker, J., van der Putten, W.H., Helder, J., 2016. Organic farming practices result in compositional shifts in nematode communities that exceed crop-related changes. Applied Soil Ecology 98, 254–260.

Reich, P.B., Hungate, B.A., Lou, Y.Q., 2006. Carbon–nitrogen interactions in terrestrial ecosystems in response to rising atmospheric carbon dioxide. Annual Review of Ecology, Evolution, and Systematics 37, 611–636.

Rodgers.W.A., Panwar, H.S., Mathur, V.B., 2000. Wildilfe Protected Area Network in India: A Review. (Executive Summary) WII, Dehradun, pp. 1–44.

Sánchez-Moreno, S., Minoshima, H., Ferris, H., Jackson, L.E., 2006. Linking soil properties and nematode community composition: effects of soil management on soil food webs. Nematology 8, 703–715.

Sechi, V., De Goede, R.G., Rutgers, M., Brussaard, L., Mulder, C., 2018. Functional diversity in nematode communities across terrestrial ecosystems. Basic and Applied Ecology 30, 76–86.

Siebert, J., Ciobanu, M., Schädler, M., Eisenhauer, N., 2020. Climate change and land use induce functional shifts in soil nematode communities. Oecologia 192, 281–294.

Sieriebriennikov, B., Ferris, H., de Goede, R.G., 2014. NINJA: an automated calculation system for nematode-based biological monitoring. European Journal of Soil Biology 61, 90–93.

Singh, G., Kachroo, P., 1978. Plant Community Characteristics in Dachigam Sanctuary, Kashmir. Natraj Publications, Dehradun.

Tsiafouli, M.A., Thébault, E., Sgardelis, S.P., De Ruiter, P.C., Van Der Putten, W.H., Birkhofer, K., Hedlund, K., 2015. Intensive agriculture reduces soil biodiversity across Europe. Global Change Biology 21, 973–985.

Turner, R.K., Van Den Bergh, J.C., Söderqvist, T., Barendregt, A., Van Der Straaten, J., Maltby, E., Van Ierland, E.C., 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35, 7–23.

Van Bezooijen, J., 2006. Methods and Techniques for Nematology. Wageningen: Wageningen University, p. 20.

van den Hoogen, J., Geisen, S., Routh, D., Ferris, H., Traunspurger, W., Wardle, D.A., Crowther, T.W., 2019. Soil nematode abundance and functional group composition at a global scale. Nature 572, 194–198.

Vazquez, C., de Goede, R.G., Korthals, G.W., Rutgers, M., Schouten, A.J., Creamer, R., 2019. The effects of increasing land use intensity on soil nematodes: A turn towards specialism. Functional Ecology 33, 2003–2016.

Verhoeven, J.T., Setter, T.L., 2010. Agricultural use of wetlands: opportunities and limitations. Annals of Botany 105, 155–163.

Wang, K. H., McSorley, R. O. B. E. R. T., Kokalis-Burelle, N., 2006. Effects of cover cropping, solarization, and soil fumigation on nematode communities. Plant and Soil, 286, 229–243.

Whitehouse, N.J., Langdon, P.G., Bustin, R., Galsworthy, S., 2008. Fossil insects and ecosystem dynamics in wetlands: implications for biodiversity and conservation. Biodiversity and Conservation 17, 2055–2078.

Wilschut, R.A., Geisen, S., 2021. Nematodes as drivers of plant performance in natural systems. Trends in Plant Science 26, 237–247.

Yang, B., Banerjee, S., Herzog, C., Ramírez, A.C., Dahlin, P., van der Heijden, M.G., 2021. Impact of land use type and organic farming on the abundance, diversity, community composition and functional properties of soil nematode communities in vegetable farming. Agriculture, Ecosystems & Environment 318, 107488.

Yeates, G.W., Bongers, T., De Goede, R.G., Freckman, D.W., Georgieva, S.S., 1993. Feeding habits in soil nematode families and genera—an outline for soil ecologists. Journal of Nematology 25, 315.

Yeates, G.W., Dando, J.L., Shepherd, T.G., 2002. Pressure plate studies to determine how moisture affects access of bacterial - feeding nematodes to food in soil. European Journal of Soil Science 53, 355–365.

Zhang, X., Guan, P., Wang, Y., Li, Q., Zhang, S., Zhang, Z., Liang, W., 2015. Community composition, diversity and metabolic footprints of soil nematodes in differently-aged temperate forests. Soil Biology & Biochemistry 80, 118–126.

Zhang, X., Ferris, H., Mitchell, J., Liang, W., 2017. Ecosystem services of the soil food web after long-term application of agricultural management practices. Soil Biology and Biochemistry, 111, 36–43.

Zhao, J., Neher, D.A., 2013. Soil nematode genera that predict specific types of disturbance. Applied Soil Ecology 64, 135–141.

Zhu, H., Mao, Z., Long, Z., Wang, Y., Su, Y., Wang, X., 2016. Effects of wetland utilization change on spatial distribution of soil nematodes in Heihe River Basin, Northwest China. Chinese Geographical Science 26, 339–351.