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Research Article

Nematode diversity and community structure assessment in different vegetations of Jammu division of J & K, India

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Abstract
Nematodes are critical for soil processes, and changes in nematode community structure have the potential to have a significant impact on ecosystem functioning. As a result, fluctuations in nematode diversity and community structure can be used to ascertain the functional biodiversity of a soil. The aim of the present study was to evaluate the effect of different vegetation and soil pH and N on nematode structure and diversity from ten different sites (Jammu, Kathua, Samba, Udhampur, Reasi, Ramban, Rajouri, Poonch, Doda, Kishtwar) of the Jammu division. The highest absolute frequency of plant parasitic nematodes (91-100%) was observed in subtropical forests in Ramban, temperate forests in Doda, while the highest absolute frequency of bacterivorous nematodes (84-87%) was observed in crop soil in Reasi and Jammu. Soil pH had a detrimental effect on nematodes; bacteriovores were abundant at low pH, and plant parasitic at higher pH. The total nitrogen content also increased in all nematode trophic groups except omnivores. Ecological indices such as the enrichment index (EI), channel index (CI) and maturity index (MI) values indicated that crop soil with organic management is more nematode-friendly and has a better soil health status than other soil ecosystems. Nematode community structure indices may be helpful as soil monitoring tools and for assessing ecosystem sustainability and biodiversity.

Keywords: Absolute frequency, Community structure, Diversity, Ecological indices, Nematode

INTRODUCTION

Nematodes are the most numerous soil dwelling organisms comprising the largest phylum in the animal kingdom in relation to diversity and abundance. They have diverse feeding habits and habitats based on which different functional groups of nematodes are developed. The functional characteristics of nematodes reveal ecosystem functioning and soil biodiversity. However, ecological research also indicates that ecosystem functioning is defined by the functional diversity or functional characteristics of organisms (Hooper *et al*., 2005, McGill *et al*., 2006). Functional characteristic-based knowledge also reveals the complexity of a community and any disturbance to ecosystems (Gross *et al*., 2017, Manning *et al*., 2018, Delgado-Baquerizo *et al*., 2020). These functional guilds (bacterivores, fungivores, omnivores, predators and plant parasitic nematodes) are provided on the basis of the types of food they rely on and their morphological structures employed for feeding (Yeates *et al*., 2009). As an essential part of ecosystems, nematodes play a key role in ecosystem functioning and soil processes, and these feeding groups may directly or indirectly be involved in C/N mineralization or nutrient fixation in soil (Ekschmitt *et al*., 1999). Soils inhabiting nematodes have a greater contribution and involvement in various ecosystem processes across variable landscapes (Yeates, 2003, Wilschut *et al*., 2019). Therefore, information on soil nematode communities at different altitudes has provided a significant relationship between soil health, climatic variables and nematode functional characteristics (Kergunteuil, 2016, Körner, 2007). Another recent study from the Himalayan Mountain range revealed the

functional role and diversity of soil nematodes, which proved to be stronger at high elevations (Kouser *et al*., 2021).

The number of characteristics, such as body size, reproduction, longevity, and tolerance level, seemed to be involved in the classification of nematodes along the colonizer-persisters scale (r- and K strategists) provided the maturity, stability and quality of the niche they occupy (Bongers, 1999). Based on this information, a diagnostic framework of the soil food web was developed (Bongers & Bongers, 1998, Ferris *et al*., 2001). The enrichment index (EI) and structure index (SI) are ecological bioindicators that may describe a significant quantitative outlook of soil conditions (Wang *et al*., 2005). Important soil nutrients, such as nitrogen, carbon, and phosphorus, are crucial for the growth and development of microbes in the soil. Among all these, nitrogen is an essential nutrient in the soil system (LeBauer and Treseder, 2008) and helps in understanding important processes such as decomposition, mineralization and nitrification (Parton *et al*., 2007). However, some edaphic factors, such as pH and sand content, have great impacts on bacterivorous nematodes (Van Den Hoogen *et al*., 2019). The capacity of water in soil and mineral components are other factors deciding the types of nematode species; hence, the community structure of nematodes is determined by soil physicochemical and abiotic factors (Goralczyk, 1998).

The aim of the present study was (i) to determine the soil nematode trophic groups belonging to disturbed and undisturbed sites in different vegetation types and (ii) to assess the impact of soil physicochemical parameters (nitrogen and soil pH) on different nematode trophic groups and their functional characteristics.

MATERIALS AND METHODS

Sample collection and sites

The current research study was conducted in the Jammu division, which is a part of the Great Himalayas and is situated in the northwestern region of the country and is geographically located between 33.2778° N and 75.3412°E. This region has various geological features and climatic variations, resulting in diverse ecosystems ranging from subtropical, temperate, alpine and subalpine regions. The temperature ranges from -5 to 38°C, and the annual mean rainfall of 8-250 mm in the surveyed region varies between subtropical and temperate and alpine regions. A total of 40 sampling sites were selected with four subsampling sites from each district, and 250 samples were taken from the soil of good organic matter, manure, agricultural fields, forests and mountainous soil at a depth of 10-15 cm by using a trowel. The collected soil samples were kept in airtight plastic bags and brought into the laboratory for further experimentation. The locations of the sampling sites viz. disturbed sites-Jammu, Kathua, Reasi, Rajouri & Poonch and undisturbed sites -Samba, Ramban, Udhampur, Doda, Kishtwar of J&K are mentioned in Fig 1, and their characteristics are provided in Table 1.

Extraction, identification and nematode enumeration

Extraction of nematodes was performed in the Nematode Biodiversity and Genomics Research Lab, Department of Zoology, BGSB University Rajouri by using

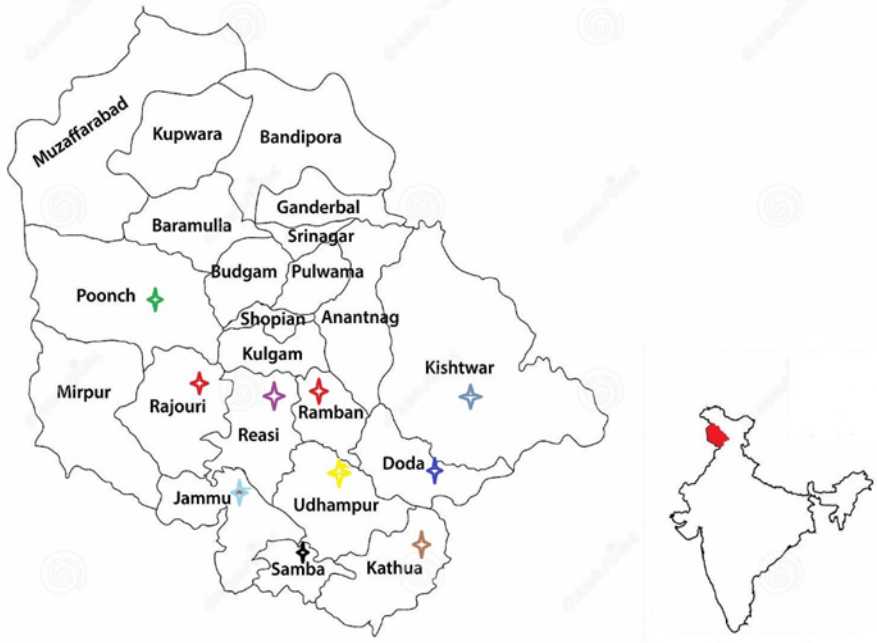

Fig.1. *Map showing the sampling from various disturbed sites (Jammu, Kathua, Reasi, Rajouri & Poonch) and undisturbed sites (Samba, Ramban, Udhampur, Doda, Kishtwar) of J&K*

modified Cobb's (1918) sieving and decantation and modified Baermann's funnel techniques at 25°C for 24 h. After extraction, isolated nematodes were taken in a cavity block under a stereomicroscope for identification and nematode enumeration. Nematodes were identified and classified on the basis of their trophic groups at the genus level using dichotomous keys (Mai and Mullin 1996, Bongers, 1988).

Soil nematode community analysis

Soil nematode communities were classified on the basis of their feeding types (Yeates *et al*., 1993). These feeding groups are bacterivores, fungivores, omnivores, predators and plant parasites, and the classification of nematodes based on life strategies are colonizers and persisters proposed by Bongers (Bongers, 1990) and Bongers *et al*. (1991). Their characterization is facilitated by analysing the diversity based on the total number of nematodes in a community (Nt) and generic richness (G), which represents the number of species per community. Frequency and absolute frequency were calculated by using the following formulas:

Frequency (N)

The number of samples in which the genus was present.

Absolute frequency (AF %)

AF% = Frequency of genus X 100/total number of samples counted. ….Eq.1

For the assessment of changes in the soil ecosystem (Table 5), ecological indices such as maturity indices (MI) and plant parasitic index (PPI) were used (Bongers, 1990). The MI was used to determine the functionality of nematodes in soil (Ferris and Bongers, 2009, Rosa and Nahum, 2012).

MI= Σvi× fi/n, where vi= c-p value of the family ….Eq. 2

where fi-frequency of family i in sample and n is the total number of individuals in a sample, while PPI was used to assess the nutrient stability (Ferris and Bongers, 2009, Rosa and Nahum, 2012).

The functional structure of the community was measured by the Wasilewska index (WI), enrichment index (EI), channel index (CI), nematode channel ratio (NCR), and structural index (SI).

The WI represents the ratio of bacterial feeders (BF) plus fungal feeders (FF) to plant parasites (PP) as

WI = (BF + FF)/PP (Wasilewska, 1994). …..Eq. 3

Nematode channel ratio (NCR): NCR is the ratio of the biomass of bacterivorous nematodes to that of fungivores and bacterivorous nematodes. Higher values indicate more fungal decomposition than bacterial decomposition.

NCR = B/B + F, where B — the abundance of bacterivorous nematodes and F- the abundance of fungivorous nematodes (Yeates, 2003) ….Eq.4

Channel index (CI)

CI represents the fungal participation in decomposition channels of soil food webs.

CI = 100* (Fu2*0.8/Ba1*3.2 +- Fu*0.8) (Ferris *et al.,* 2001). ….Eq. 5

Enrichment index (EI)

The EI represents the total biomass of opportunistic bacterivorous (Ba1 and Ba2) and fungivorous (Fu2) nematodes that rise from the decomposition of organic matter (Ferris *et al*., 2001).

Table 1. Sampling sites and their characteristics

Districts	Vegetation types	Latitude and longitude	Elevation (m.a.s.l.)
A) Jammu (J1)	Mixed cropping; monocropping and garden soil	32" 54 N 74" 44 E	297-348
B) Kathua (K3)	Monocropping and mixed cropping	32" 42 N	318-1291
C) Samba (S1)	Trees, shrubland and herbs	32" 33 N	334-358
D) Udhampur	Grassland	32" 48 N	560-1119
E) Ramban (RM2)	Forests	33" 20 N 75" 11 E	880-1578
F) Reasi (RS3)	Monocropping and mixed cropping	32" 59 N	529-903
G) Rajouri	Trees and compost	33" 28 N	594-1547
H) Poonch (P1)	Temperate forests and alpine forests	33" 34 N	943-3497
I) Doda (D4)	Temperate forests	32" 58 N	662-1632
J) Kishtwar	Temperate forests	33" 10 N	1054-1630

EI = 100* e/e + b ….Eq. 6
where e = (Ba1*3.2) + (Fu2*0.8), b= (Ba2+Fu2)0.8

Structural index (SI)

SI represents the food web status affected by disturbance or stress (Ferris *et al*., 2001).

SI = 100* s/s + b ….Eq. 7
where s = Ban + Prn + Fun + Omn,n=3–5 and b =Ba2+ Fu2 (Ba-bacteriovorous, Pr-Predatory, Fu-fungivorous & Om-omnivorous nematodes)

Physical and chemical analysis of soil

Soil physicochemical analyses were carried out at the Nematode Biodiversity and Genomics Research Lab, Department of Zoology (Baba Ghulam Shah Badshah University, Rajouri). For pH analysis, the pH meter was calibrated first, and then 20 g of soil from each sample was dissolved in 100 ml of distilled water with continuous stirring to make a suspension for half an hour and kept undisturbed. Then, the pH reading of each sample was recorded and displayed on the pH meter. Total nitrogen (TN) was determined by the micro- Kjeldahl distillation method (Bremner, 1996).

Statistical analysis

Analysis of variance was used to determine the significance of the variables studied. For this, a one-way ANOVA model was used separately for each factor, where each nematode trophic group and soil nutrients, such as nitrogen and soil pH, were used as a factor of analysis. Significance between nematode groups was considered at $P \leq 0.05$.

RESULTS

Nematode composition

A total of 77 genera were recorded (Table 2) from both disturbed and undisturbed vegetation types, representing bacterivores with the highest absolute frequency in disturbed vegetation types and plant parasites with the highest absolute frequency in undisturbed vegetation types (Table 3). Among the bacterivores, Rhabditida had the highest percentage, followed by Tylenchida, Dorylaimida and Monochida in disturbed vegetation types, while Tylenchida was followed by Mononchida, Dorylaimida and Rhabditida with the lowest percentage in undisturbed vegetation types (Table 3).

Higher nitrogen percent in the soil system of disturbed sites of rice fields (Jammu), wheat fields (Kathua) and mixed crops (Reasi) and compost soil (Rajouri), increased the frequency and absolute frequency of bacterivorous nematodes, while undisturbed soil systems of grassland (Udhampur), tress (Samba), subtropical forests (Ramban) and temperate forest (Doda) and alpine forest (Kishtwar) enhanced the growth of other trophic groups (predators, omnivores, fungivores, plant parasitic nematodes) under low nitrogen percent in soil (Table 3).

N-enriched soil occupied a higher abundance of bacterivorous nematodes within c-p values of 1-2, consisting of Rhabditidae, Diplogasteridae, and Diploscapteridae. Still, the N-depleted soil consisted of few bacterivores and more omnivorous nematodes belonging to Dorylaimidae, Nordiidae, Leptonchidae, and Belondiridae. In contrast, moderate N-enriched soil had domi-

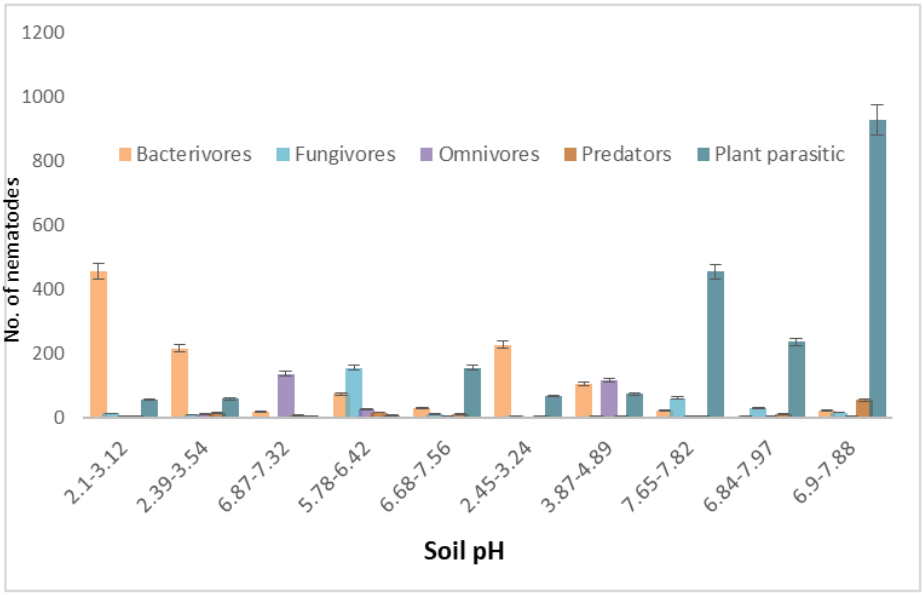

Fig. 2. *Nematode trophic guilds in different vegetation types (Rice fields-Jammu, Wheat fields-Kathua, Trees-Samba, Grasslands-Udhampur, Subtropical forests-Ramban, Mixed crops-Reasi, Compost-Rajouri, Vegetable fields-Poonch, Temperate forests-Doda, Alpine forests-Kishtwar) of Jammu divsion under different pH range.*

Table 2. Total soil nematodes genera isolated from different vegetation types

Nematode genera	c-p values	Nematode genera	c-p values
Acrobeloides	2	*Eudorylaimus*	4
Ablechroiulus	1	*Laimydorus*	4
Amphidelus	1	*Mesodorylaimus*	4
Anaplectus	1	*Microdorylaimus*	4
Aulolaimus	1	*Belondirella*	4
Acrobeles	2	*Belondira*	4
Alaimus	1	*Dorylaimoides*	4
Bunonema	1	*Labronema*	4
Bursilla	1	*Prodorylaimus*	4
Cephalobus	2	*Anatonchus*	4
Cheilorhabditis	1	*Clarkus*	5
Cruznema	1	*Iotonchus*	5
Curviditis	1	*Mononchus*	5
Cuticularia	1	*Mononchoides*	5
Diplogaster	1	*Mylonchulus*	5
Diploscapteroides	1	*Odontopharynx*	5
Diploscapter	1	*Paramylonchulus*	5
Diplogasteritus	1	*Parahadronchus*	5
Leptolaimus	2	*Miconchus*	5
Mesodiplogaster	1	*Prionchulus*	5
Mesorhabditis	1	*Anguina*	2
Rhabditis	1	*Criconema*	3
Pelodera	1	*Cephalenchus*	1
Protorhabditis	1	*Hoplolaimus*	3
Rhabpanus	1	*Ditylenchus*	2
Rhabditoides	1	*Malenchus*	2
Rhabditophanes	1	*Meloidogyne*	3
Teratorhabditis	1	*Longidorus*	5
Wilsonema	2	*Pratylanchus*	3
Aphelenchoides	2	*Globodera*	
Aphelenchus	2	*Heterodera*	
Tylaphelenchus	2	*Helicotylenchus*	3
Bursaphelenchus	2	*Psilenchus*	2
Hexatylus	2	*Tylenchorhynchus*	3
Tylencholaimus	2	*Tylenchus*	2
Tylencholaimellus	2	*Gracilacus*	2
Amphidorylaimus	4	*Xiphinema*	5
Dorylaimus	4	*Rotylenchus*	3

c-p : Colonisers-Persisters

Table 3. Datasets of frequency and absolute frequency of nematode genera in disturbed and undisturbed sites of Jammu division

	J1		K3		P1		RS3		RJ4	
	F	AF	F	AF	F	AF	F	AF	F	AF
Bacterivores										
Acrobeloides	3	10	0	0	0	0	6	18.2	2	2.5
Ablechroiulus	21	70	5	25	2	6.25	22	66.7	4	5
Amphidelus	13	43.33	7	35	1	3.13	15	45.5	1	1.25
Anaplectus	10	33.33	8	40	2	6.25	14	42.4	0	0
Aulolaimus	16	53.33	12	60	1	3.13	11	33.3	8	10
Acrobeles	10	33.33	14	70	1	3.13	25	75.8	5	6.25
Alaimus	8	26.67	11	55	0	0	23	69.7	4	5
Bunonema	10	33.33	10	50	2	6.25	16	48.5	2	2.5
Bursilla	12	40	6	30	1	3.13	17	51.5	6	7.5
Cephalobus	7	23.33	15	75	0	0	18	54.5	4	5
Cheilorhabditis	13	43.33	5	25	0	0	10	30.3	0	0
Cruznema	9	30	13	65	2	6.25	17	51.5	1	1.25
Curviditis	14	46.67	7	35	1	3.13	8	24.2	3	3.75
Cuticularia	22	73.33	12	60	1	3.13	22	66.7	1	1.25
Diplogaster	3	10	10	50	0	0	20	60.6	2	2.5
Diploscapteroides	5	16.67	13	65	1	3.13	14	42.4	1	1.25
Diploscapter	14	46.67	17	**85**	0	0	8	24.2	0	0
Diplogasteritus	3	10	10	50	0	0	9	27.3	0	0
Leptolaimus	18	60	13	65	1	3.13	5	15.2	0	0
Mesodiplogaster	6	20	10	50	1	3.13	7	21.2	1	1.25
Mesorhabditis	9	30	15	75	1	3.13	4	12.1	0	0
Rhabditis	5	16.67	10	50	1	3.13	25	75.8	1	1.25
Pelodera	12	40	11	55	0	0	28	**84.8**	2	2.5
Protorhabditis	9	30	13	65	0	0	10	30.3	1	1.25
Rhabpanus	26	**86.67**	8	40	0	0	24	72.7	0	0
Rhabditoides	6	20	15	75	0	0	28	84.8	1	1.25
Rhabditophanes	16	53.33	7	35	1	3.13	7	21.2	2	2.5
Teratorhabditis	18	60	8	40	1	3.13	13	39.4	4	5
Wilsonema	14	46.67	6	30	0	0	5	15.2	0	0
				0		0		0		0
Fungivores		0		0		0		0		0
Aphelenchoides	1	3.333	4	20	20	62.5	1	3.03	2	2.5
Aphelenchus	0	0	6	30	24	75	0	0	1	1.25
Tylaphelenchus	0	0	1	5	15	46.9	1	3.03	0	0
Bursaphelenchus	1	3.333	0	0	16	50	3	9.09	1	1.25
Hexatylus	2	6.667	3	15	29	90.6	2	6.06	0	0
Tylencholaimus	1	3.333	3	15	25	78.1	1	3.03	2	2.5
Tylencholaimellus	3	10	2	10	28	87.5	0	0	1	1.25
				0		0		0		0
Omnivores				0		0		0		0
Amphidorylaimus	3	10	1	5	2	6.25	0	0	55	68.75
Belondirella	0	0	0	0	0	0	0	0	28	35
Belondira	0	0	0	0	0	0	0	0	31	38.75
Dorylaimoides	0	0	0	0	0	0	0	0	52	65
Dorylaimus	2	6.667	0	0	4	12.5	1	3.03	25	31.25
Eudorylaimus	0	0	3	15	1	3.13	0	0	42	52.5
Labronema	0	0	0	0	0	0	0	0	35	43.75
Laimydorus	0	0	4	20	3	9.38	1	3.03	40	50
Mesodorylaimus	1	3.333	2	10	2	6.25	1	3.03	46	57.5
Microdorylaimus	0	0	0	0	0	0	1	3.03	37	46.25
Prodorylaimus	0	0	0	0	0	0	0	0	49	61.25

Contd……..

Table 3. Contd…….

Predators		0		0		0		0		0
Anatonchus	2	6.667	3	15	2	6.25	0	0	2	2.5
Clarkus	0	0	4	20	1	3.13	1	3.03	1	1.25
Iotonchus	0	0	5	25	2	6.25	0	0	0	0
Mononchus	1	3.333	1	5	0	0	1	3.03	0	0
Mononchoides	2	6.667	0	0	3	9.38	0	0	0	0
Mylonchulus	1	3.333	0	0	4	12.5	0	0	0	0
Odontopharynx	1	3.333	2	10	2	6.25	2	6.06	1	1.25
Paramylonchulus	0	0	3	15	5	15.6	0	0	2	2.5
Parahadronchus	0	0	1	5	1	3.13	1	3.03	0	0
Miconchus	0	0	0	0	0	0	2	6.06	1	1.25
Prionchulus	1	3.333	2	10	0	0		0	0	0
Plant parasitic										
Anguina	6	20	7	35	2	6.25	13	39.4	5	6.25
Criconema	8	26.67	15	75	1	3.13	10	30.3	4	5
Cephalenchus	5	16.67	11	55	1	3.13	6	18.2	0	0
Hoplolaimus	4	13.33	9	45	1	3.13	9	27.3	3	3.75
Ditylenchus	7	23.33	12	60	0	0	21	63.6	1	1.25
Malenchus	4	13.33	15	75	1	3.13	14	42.4	2	2.5
Meloidogyne	2	6.667	16	80	0	0	12	36.4	1	1.25
Longidorus	3	10	17	85	2	6.25	10	30.3	2	2.5
Pratylanchus	7	23.33	0		1	0	0	0	1	1.25

	Undisturbed sites									
	S1		**RM2**		**U1**		**D4**		**KS2**	
	F	**AF**	**F**	**AF**	**F**	**AF**	**F**	**AF**	**F**	**AF**
Bacterivores										
Acrobeloides	3	20	4	11.76	1	1.67	0	0	2	3.33
Ablechroiulus	4	26.67	1	2.941	0	0	1	5	3	5
Amphidelus	1	6.667	0	0	0	0	0	0	1	1.67
Anaplectus	2	13.33	3	8.824	0	0	0	0	2	3.33
Aulolaimus	0	0	1	2.941	1	1.67	2	10	5	8.33
Acrobeles	0	0	1	2.941	2	3.33	1	5	2	3.33
Alaimus	0	0	2	5.882	0	0	0	0	0	0
Bunonema	0	0	4	11.76	2	3.33	2	10	1	1.67
Bursilla	0	0	1	2.941	6	10	3	15	2	3.33
Cephalobus	1	6.667	0	0	4	6.67	2	10	3	5
Cheilorhabditis	1	6.667	1	2.941	0	0	0	0	2	3.33
Cruznema	1	6.667	0	0	1	1.67	1	5	2	3.33
Curviditis	0	0	1	2.941	1	1.67	3	15	0	0
Cuticularia	0	0	0	0	0	0	1	5	1	1.67
Diplogaster	0	0	1	2.941	2	3.33	2	10	2	3.33
Diploscapteroides	2	13.33	3	8.824	1	1.67	1	5	1	1.67
Diploscapter	3	20	5	14.71	1	1.67	0	0	0	0
Diplogasteritus	1	6.667	0	0	0	0	1	5	0	0
Leptolaimus	1	6.667	2	5.882	1	1.67	1	5	0	0
Mesodiplogaster	0	0	0	0	1	1.67	0	0	1	1.67

Contd……..

Table 3. Contd…….

Mesorhabditis	0	0	1	2.941	0	0	1	5	0	0
Rhabditis	0	0	0	0	1	1.67	2	10	0	0
Pelodera	1	6.667	2	5.882	2	3.33	2	10	0	0
Protorhabditis	2	13.33	1	2.941	1	1.67	0	0	2	3.33
Rhabpanus	0	0	0	0	2	3.33	0	0	1	1.67
Rhabditoides	2	13.33	1	2.941	1	1.67	1	5	3	5
Rhabditophanes	0	0	2	5.882	0	0	2	10	2	3.33
Teratorhabditis	0	0	1	2.941	1	1.67	2	10	5	8.33
Wilsonema	0	0	0	0	0	0	1	5	2	3.33
Fungivores										
Aphelenchoides	1	6.667	1	2.941	42	70	3	15	8	13.3
Aphelenchus	0	0	1	2.941	39	65	0	0	5	8.33
Tylaphelenchus	0	0	1	2.941	22	36.7	1	5	7	11.7
Bursaphelenchus	0	0	4	11.76	25	41.7	0	0	6	10
Hexatylus	0	0	0	0	36	60	1	5	2	3.33
Tylencholaimus	1	6.667	0	0	42	70	0	0	2	3.33
Tylencholaimellus	2	13.33	7	20.59	52	86.7	2	10	0	0
Omnivores										
Amphidorylaimus	11	73.33	2	5.882	2	3.33	2	10	3	5
Belondirella	0	0	0	0	0	0	0	0	0	0
Belondira	0	0	0	0	0	0	0	0	0	0
Dorylaimoides	0	0	0	0	0	0	0	0	0	0
Dorylaimus	14	93.33	1	2.941	5	8.33	5	25	2	3.33
Eudorylaimus	13	86.67	0	0	0	0	3	15	0	0
Labronema	0	0	0	0	0	0	0	0	0	0
Laimydorus	15	100	2	5.882	5	8.33	4	20	2	3.33
Mesodorylaimus	14	93.33	1	2.941	6	10	1	5	1	1.67
Microdorylaimus	13	86.67	0	0	8	13.3	0	0	0	0
Prodorylaimus	0	0	0	0	0	0	0	0	0	0
Predators										
Anatonchus	2	13.33	1	2.941	2	3.33	3	15	9	15
Clarkus	1	6.667	2	5.882	3	5	2	10	12	20
Iotonchus	0	0	1	2.941	1	1.67	0	0	10	16.7
Mononchus	1	6.667	1	2.941	0	0	1	5	14	23.3
Mononchoides	0	0	1	2.941	6	10	1	5	7	11.7
Mylonchulus	1	6.667	2	5.882	0	0	2	10	11	18.3
Odontopharynx	2	13.33	1	2.941	5	8.33	0	0	6	10
Paramylonchulus	1	6.667	1	2.941	2	3.33	1	5	8	13.3
Parahadronchus	1	6.667	1	2.941	1	1.67	0	0	9	15
Miconchus	0	0	1	2.941	0	0	2	10	6	10
Prionchulus	0	0	0	0	0	0	0	0	13	21.7

Table 3. Contd…….

Plant parasitic										
Anguina	0	0	20	58.82	28	46.7	12	60	30	50
Criconema	0	0	19	55.88	30	50	10	50	24	40
Cephalenchus	1	6.667	16	47.06	20	33.3	13	65	16	26.7
Hoplolaimus	1	6.667	34	**100**	23	38.3	0	0	0	0
Ditylenchus	2	13.33	29	85.29	29	48.3	19	95	19	31.7
Malenchus	0	0	27	79.41	13	21.7	0	0	18	30
Meloidogyne	1	6.667	16	47.06	10	16.7	20	**100**	16	26.7
Longidorus	2	13.33	31	**91.18**	18	30	16	80	27	45
Pratylanchus	1	6.667	30	88.24	14	23.3	13	65	24	40
Globodera	0	0	0	0	0	0	10	50	0	0
Heterodera	0	0	0	0	0	0	17	85	0	0
Helicotylenchus	0	0	0	0	0	0	20	**100**	19	31.7
Psilenchus	0	0	0	0	0	0	18	90	0	0
Tylenchorhynchus	0	0	0	0	0	0	16	80	0	0
Tylenchus	0	0	0	0	0	0	0	0	29	48.3
Gracilacus	0	0	0	0	0	0	0	0	20	33.3
Xiphinema	0	0	0	0	0	0	0	0	26	43.3
Rotylenchus	0	0	0	0	0	0	0	0	25	41.7

Sites: Jammu-J1, Kathua-K3, Samba-S1, Udhampur-U1, Ramban-RM2, Reasi-RS3, Rajouri-RJ4, Poonch-P1, Doda-D4, Kishtwar-KS2; F-Frequency, AF-Absolute frequency

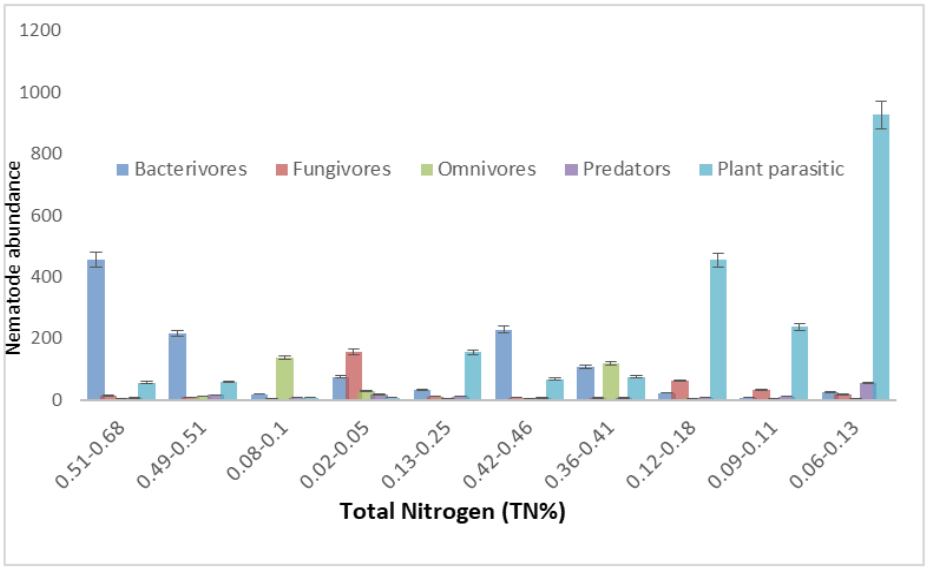

Fig. 3. *Effect of total nitrogen on different nematode trophic guilds*

nant plant parasitic nematodes belonging to Pratylenchidae, Psilenchidae, Longidoridae, Meloidogynidae, Rotylenchidae, Anguinidae, Hoplolaimidae, and Tylenchulidae, including some other trophic groups (Table 2).

At higher pH, plant parasitic nematodes were higher, and at lower pH, bacterivorous nematodes were found to be higher (Fig. 2). At a higher percent of nitrogen, bacterivores were observed to be higher, and at a lower N percentage, plant parasitic nematodes were found to be higher (Fig. 3). Both soil parameters had a significant effect (p-value <0.05) on nematode trophic groups. Total nematode abundance was highest in site KS2 (Kishtwar) and lowest in site S1 (Samba) (Fig. 4).

Nematode community indices

In sites J1(Jammu), K3(Kathua) and RS3(Reasi) high level of disturbance, N enriched, with bacterial decom-

position pathway dominated by bacterivores nematodes were observed while in sites of S1(Samba), U1 (Udhampur), RM2(Ramban), RJ4(Rajouri), P1(Poonch) D4(Doda), and KS2(Kishtwar) have low to moderate disturbance, moderate nitrogen percent, and dominated fungal decomposition pathway along with other trophic groups was observed (Table 4). Maturity indices differ from one site to other, as higher MI was seen at sites J1, K3, and RS3 and lower MI was seen at sites S1, U1 and RM2. EI differed from disturbed to undisturbed sites, with higher EI in highly N-enriched soil than in other soil systems. The CI was lower in the cropping system and found to be moderate to higher in the less disturbed sites, while the SI and BI were lower in the cropping system and higher in the other soil systems (Table 4).

DISCUSSION

Extracted soil nematodes act as an important indicator of soil food web status and important ecological soil functioning. These nematodes are highly sensitive to soil changes and are influenced by changes in pH and soil nitrogen (TN%). Specifically, N-enriched and low pH sites offer different soil communities and functions. Briefly, many functional groups of soil nematodes that can lead to the analysis of functional indices are explained.

Bacterivores and fungivorous nematodes

Bacterivore nematodes showed a positive and significant correlation with soil organic matter and nitrogen (Thuo *et al*., 2020). Organic amendments in the soil

Table 4. Nematode community indices in different sites of Jammu division.

Sites	MI	PPI	PPI/MI	NCR	WI	EI	SI	CI
J1	1.258	2.82	2.24	27.88	8.31	90.9	54.54	4.91
K3	1.596	2.83	1.779	0.955	3.783	90.17	60.49	4.96
S1	3.66	3	0.819	0.833	3	83.78	80	9.62
U1	2.19	2.55	1.164	0.323	25.77	86.3	66.7	11.11
RM2	2.31	2.53	1.095	0.733	0.288	83.29	66.6	6.49
RS3	1.33	2.63	1.9774	0.966	3.434	90.9	61.5	4.9
RJ4	2.009	2.74	1.366	0.938	1.52	88.76	70.5	8.86
P1	0.838	2.71	3.23	0.275	0.19	86.3	66.8	11.11
D4	2.631	2.78	1.05	0.2	0.168	84.8	80.3	14.21
KS2	3.042	2.71	0.89	0.58	0.046	88.09	61.5	8.16

Sites: Jammu-J1, Kathua-K3, Samba-S1, Udhampur-U1, Ramban-RM2, Reasi-RS3, Rajouri-RJ4, Poonch-P1, Doda-D4, Kishtwar-KS2

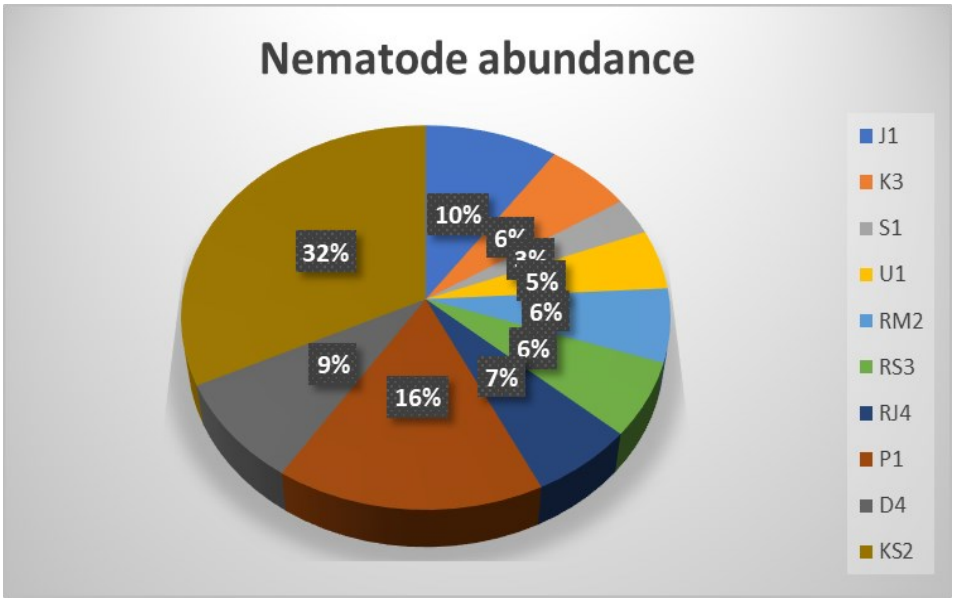

Fig. 4. *Abundance of soil nematode trophic groups in ten different sites (J1-Jammu, K3-Kathua, S1-Samba, U1-Udhampur, RM2-Ramban, RS3-Reasi, RJ4-Rajouri, P1-Poonch, D4-Doda, KS2-Kishtwar)*

Table 5. Characteristics of soil ecosystem functioning

General characteristics	J1	K3	S1	U1	RM2	RS3	RJ4	P1	D4	KS2
Vegetation	Rice fields	Wheat fields	Trees	Grassland	Subtropical forests	Mixed crops	Compost	Vegetables	Temperate forests	Alpine forests
Disturbance	High	High	Low	Low	Low	High	Moderate	Moderate	Low	Low
Trophic groups	BAC	BAC	PPN	OMN	PPN	BAC	BAC, OMN	BAC, FUN	PPN	PPN
Enrichment	N-enriched	N-enriched	Moderate	Moderate	Moderate	N-enriched	Depleted	Moderate	Moderate	Moderate

Sites: Jammu-J1, Kathua-K3, Samba-S1, Udhampur-U1, Ramban-RM2, Reasi-RS3, Rajouri-RJ4, Poonch-P1, Doda-D4, Kishtwar-KS2

help the bacteria proliferate and grow rapidly as the bacteria are nourished from dead organic matter (Liang *et al*. 2009). Other studies revealed that bacterivores Ba1 and Ba2 showed positive correlations with total nitrogen and organic carbon and available P in the soil (Pan *et al*, 2010, Sánchez-Moreno *et al*., 2008, Nisa *et al*., 2021). Our results are consistent with those of Fu *et al*. (2005), who found bacterivorous nematodes were more abundant in N-enriched soil where the organic matter decomposition pathway was dominated by bacteria that are involved in nutrient cycling (Fig. 3). The association of nematodes with their soil environments helps us assess soil health and soil functioning, such as nutrient availability and microbial communities (Mulder *et al*., 2005, Chung *et al*., 2007). This is consistent with our findings that bacterivorous nematodes are highly impacted by nutrient enrichment. The use of fertilizers in crops and remains of crops enhances the reproduction and growth of bacterivores cp1 (Ferris *et al*., 2004, Bulluck Iii *et al*., 2002), which is consistent with our findings where the frequency and absolute frequency of bacterivorous nematodes in crop soil was high, which may be due to the increased bacterial decomposition in crop soil (Table 3). Our results match those of (Cerasez *et al*., 2015), where fungivorous nematodes are r-strategists (Fu2), decrease with the increase in nitrogen in the soil and increase with the increase in carbon in the soil (Fig. 3). Another study indicated that certain species of the fungivorous nematodes *Achromadora*, *Tylenchorrynchus*, *Cervidellus* and *Plectus* increase with increasing soil pH and phosphorus (Thuo *et al*., 2020).

Omnivore nematodes and predatory nematodes

Omnivores and predatory nematodes are k strategists who are less tolerant and survive at less nutrients in soil and inhabit positions at top trophic levels and often become indicators of more species richness and trophic links, which is represented by the SI (Ferris *et al*., 2001). Cesarz *et al*. (2015) reported that omnivore nematodes are less affected by changes in nitrogen content in the soil, but predators are reduced in their number at higher nitrogen contents, which is consistent with our results (Fig 3). Omnivorous nematodes have varied feeding habits and are not exactly known but interact with other microbes at different levels of the soil food web (Hanel, 2003). However, their number is increased in more carbon and soil organic matter (SOM) (Thuo *et al*., 2020).

Plant parasitic nematodes

Cesarz *et al*. (2015) reported a decrease in PPNs at high levels of carbon and nitrogen and a significant reduction in their number under disturbance, which is consistent with our findings, as fewer plant parasitic nematodes were found at disturbed sites, which may

be due to the high nitrogen content in crop soil (Table 3). Most PPN genera decreased at more total nitrogen, with the exception of a few *Aphelenchoides*, *Ditylenchus*, and *Criconema*, because nitrogen accumulation in the soil through the nitrate and ammonical nitrogen becomes toxic to PPNs (Rodriguez-Kabana *et al*., 1981, Rodriguez-Kabana, 1986).

Functional indices

MI represents the condition of the soil system and soil disturbances (Bongers, 1990), and its value depicts soil intrusion due to the addition of fertilizers in the soil (Bongers *et al*., 1997). Current studies reveal that crop fields such as rice, wheat and mixed crops (vegetable fields) are highly fertilized soil systems with lower MI values than other undisturbed soils of forests and grasslands (Table 4). A higher value of the maturity index (MI) in natural/undisturbed soils was found and seasonally affected because of changes in soil temperature and humidity (Thuo *et al*., 2020).

The EI signifies the enrichment of opportunists compared to the other groups, ultimately depicting resource enrichment that indicates soil productivity (Ferris *et al*., 2001). The current study revealed a low EI value in undisturbed sites and a higher EI in disturbed systems, which is consistent with the findings of Ferris *et al*. (2001). Ugarte *et al*., 2013 reported a higher value of EI in the region where the bacterial decomposition pathway was highly dominant (which is consistent with the present results that the enrichment index in disturbed sites was higher, which may be due to more bacterivores in the soil system (Table 4).

The current findings reported that lower CI values were associated with N-enriched sites (Table 4), which is comparable to previous findings of Pan *et al*. (2015) and Azpilicueta *et al*. (2014), which showed lower CI values in N-enriched plots than in control plots. Lower CI values indicate that N-enriched soil leads the soil food web to form bacterial decomposition channels.

According to Thuo *et al*. (2020), structure index (SI) indices showed greater variation in different seasons, and higher values of SI were found in the natural soils, which is consistent with our results that the structure index in undisturbed soil was high, which is probably due to the less human intervention that ultimately prevented biodiversity loss (Table 4).

Conclusion

Different trophic groups, such as bacterivores, fungivores, omnivores, predators and plant parasitic nematodes, existed at different concentrations of nutrients, disturbances, and vegetation types. They responded to the level of disturbances in the soil and were sensitive to any change in soil conditions. Bacterivorous nematodes were abundant in disturbed vegetation types, and plant parasitic nematodes were abundant in undisturbed vegetation. The soil edaphic factors pH and total nitrogen content are detrimental factors affecting nematode abundance and diversity. Nematode abundance and diversity were higher in vegetations with higher N content, while increased pH increased the number of plant parasitic nematodes and decreased the number of bacterivorous nematodes. The results of this work may prove to be fruitful for ecologists, biologists and taxonomists for important implications in ecosystem processes and soil functioning.

Conflict of interest

The authors declare that they have no conflicts of interest.

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