Research Article

Biological indicative assessment of nematodes in evaluating different terrestrial habitats

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ABSTRACT

Healthy soil ecosystem plays crucial role maintaining global biosphere and developing sustainable agricultural practices. Land exploitation and improper agricultural practices greatly impact the soil health quality in time and space. Understanding the effects of organic and inorganic enrichments on soil quality and its indicators has been identified as one of the most important goals for modern soil science. For the present study, we compared the differences in the nematode diversity of healthy undisturbed soil with soil enriched with organic amendments and inorganic amendments. Soil samples were collected from three different habitats *viz.*, organic enriched soil, inorganic enriched soil and undisturbed soil in rural and urban areas. Nematode community structure was studied in terms of frequency, density, biomass, trophic diversity and other common diversity or ecological indices. A total of 56, 61 and 72 nematode genera/species were identified in organic enriched, inorganic enriched and undisturbed soil. Shannon's diversity index (H′) values were higher in undisturbed habitat than organic and inorganic enriched soil indicated that diversity of species was highest in undisturbed habitats. The Maturity index (MI), Structure Index (SI) was lowest and Enrichment Index (EI) was highest for organic and inorganic enriched soil revealed unstable and disturbed ecosystem. While in undisturbed habitats MI, SI were high and EI was lowest reflect stable and structured ecosystem. This study will provide a base for stakeholders mainly in land use and sustainable agricultural practices and serves as a triggering mechanism for implementation of soil contamination mitigating strategies.

Keywords: Bioindicator; Diversity indices; Enriched soil; Nematode community; Soil quality; Trophic group.

INTRODUCTION

Twenty first century main concern is the impact of anthropogenic activities such as industrialization, urbanization and extensive agricultural practice using inorganic fertilizers and pesticide. Agents that affect soil health are added to the soils by various anthropogenic activities can build up to concentrations that build and change microbial biota and eventually affects the plant and animal health (Alloway, 1995). The nematode community analyses upto species level reveals insight into the environmental ecosystem structure and function where a larger and more diverse assemblages reflect a capacity to perform ecological functions and thus sustain soil productivity and health (Yeates, 1997). Functional or trophic groups of nematodes can be explained as groups of species that have similar kinds of effects on ecosystem processes such as anthropogenic disturbance (Chapin *et al*., 1992). A change in their community composition in the soil food web reflects changes in environmental conditions (Bongers and Ferris 1999, Wasilewska, 1994; Thornton and Matlack 2002; Wall *et al*., 2002). The ecologists generally recognize the following five major trophic groups among soil inhabiting nematodes based on the nature of their feeding habit and structure of feeding apparatus *viz.*, Bacteriovores, Fungivores, Herbivores, Omnivores and predators (Yeates *et al.,* 1993; Yeates, 1998; Yeates and Bongers, 1999). Nematodes viewed as indicators of soil ecosystem resilience due to the presence of these multiple trophic participating in soil food webs and play important role in nutrient recycling. Their diverse life history strategies may indicate whether the ecosystem has experienced a recent disturbance e.g. large-bodied omnivores and predators are persistent k-strategists, whereas bacterivores and fungivores are smaller, more numerous and respond to environmental perturbations as r-strategists (Bongers and Bongers, 1998). Bacterivores in the families Rhabditidae and Cephalobidae reflect changes in soil ecological functions due to the tendency of the Rhabditidae to increase following nutrient inputs, while the ubiquitous Cephalobidae increase in abundance during primary and secondary succession (Yeates, 2003). Use of mainly inorganic ammendments in agricultural land causes soil ecosystem dsturbnce and reflected by different communities of microorganisms residing in the soil (Fließbach and Mäder, 2000; Yeates, 2003; Giola *et al*., 2012; Oloyede, 2012; Liu *et al*., 2013; Khan *et al*., 2014).

Soil nematodes, as a major mesofauna of soil food webs provides a wide range of ecosystem services including organic material decomposition, cycling of mineral nutrients, regulation of pest species and energy of transfer (Hättenschwiler et al., 2005; Wall et al., 2012; Coleman and Wall, 2015). Indeed, nematodes communities provides information on changes in different decomposition pathways in the soil food web, nutrient status, fertility and acidity of the soil and the effect of pollutants in the soil ecosystem (Hohberg 2003; Elmer *et al.,* 2013; Li *et al.,* 2016; Franco *et al.,* 2017; Bokhorst *et al.,* 2017.

Ecological indices of nematode assemblages used to describe changes in soil ecological functions are: (1) maturity index (MI) to assess the free-living nematodes response to stress, where higher values represent a more stable community (Neher, 2010), (2) Enrichment index (EI) to indicate the availability of food resources and measure the increase in small-bodied opportunistic bacterial and fungal feeders that respond quickly to C and N inputs, and (3) Structure index (SI), where higher values suggest more linkages in the food web and greater soil resilience (Ferris et al., 2001). Soil monitoring using nematodes is feasible, less expensive method for study of regional variations and the anthropogenic contamination that destruct the soil health such various toxic organic and inorganic compounds and heavy metals in soil. Bio monitoring provides a direct measure of biological effect rather than inferring values using expensive soil extractions (Tarazona et al.*,* 2005). The information generated by studying nematode community structure proved to be greatly useful for the conservation, monitoring and remediation processes of ecosystem (Stone *et al*., 2016). It will help the stakeholders for environmental planning and monitoring in rural and urban area. Based on holistic nematode community analysis of different habitats the highest risk sites can be identified in which the remediation activity and monitoring should take place. The major objective of the present study was the biomonitoring of soil quality of selected habitats in rural and urban areas in various district of Uttar Pradesh. Nematode community analysis provides feasible method for assessing and mapping soil quality changes in time and space in small units.

MATERIALS AND METHODS

Site description, soil sampling and nematode extraction

The samples were randomly collected from soil enriched with organic amendments (soil with organic decomposing matter), inorganic industrial effluents and inorganic fertilizers used in agricultural fields and from healthy undisturbed soil ecosystemfrom different districts of the Western Uttar Pradesh, which forms the fifth largest and most populous state of India's. It includes highly fertile Rohilkhand plain, upper, middle and part of lower Ganga-Yamuna doab region. The region holds distinction from other parts of the country in its demographic, economic and cultural patterns It falls within the coordinates 29° 58′ 12″ N to 26° 28′ 12″

N along the latitude and 77° 35′ 0″ E to 80° 6′ 0″ E along the longitude.

Sampling sites

1. Soil samples were randomly collected from different three habitats that are rich in organic manure, dead and decaying plant material or leaf litter, compost, dung, rotten wood, tree holes in year, from 2016-18.

2. Soil collected from nearby drains from local industries paper industries, metal industries and dyes industries that contain inorganic compounds/chemicals as effluents. And also form fields that are treated with inorganic nitrogen fertilizer only; inorganic nitrogen, phosphorus and potassium fertilizers; and organic fertilizer plus inorganic nitrogen, phosphorus and potassium fertilizers.

3. Soil samples collected from natural undisturbed habitat like forest patches located in the region.

Sixty samples collected from each habitat making 180 soil samples and each sample represented a thoroughly mixed composite sample of three replicate sub-samples which makes total 540 samples. The samples were collected by digging out soil from pit of 5 cm diameter and 20 cm depth and were stored in sealed plastic bags brought to laboratory for further processing. The samples were processed by modified Cobb's (1918) sieving, decantation and modified Baerman's funnel technique for isolation of nematodes.

Nematode identification, counting, community analysis and diversity indices

The freshly extracted nematodes were examined under stereoscopic microscope (BX-41) and mass slides containing one hundred nematodes per sample were prepared for identification at the generic level. Identification up to generic level was done mainly using Goodey (1963); Jairajpuri and Khan (1982); Andrássy (1984), Siddiqi (1986), Jairajpuri and Ahmad (1992); Ahmad (1996). Trophic group and cp values were allocated according to Yeates *et al.* (1993).

Identification at species level were done by studying their permanent mounts after fixation by F:A fixation and dehydration in glycerine alcohol (95 parts of 30% alcohol + 5 parts of glycerol). Counting of each sample was done thrice and mean was obtained. The individual species population and the total count of nematode were used for calculation of various indices. The basic statistical parameters *viz*., frequency, relative frequency, density, relative density, mean biomass (Andrássy, 1956) and relative biomass (Norton, 1978), the various diversity and food web indices were calculated.

The following parameters were used:

Frequency (N): Frequency of nematode genus (*i.e*., the number of samples in which the genus was present).

Absolute frequency (AF%): (Frequency of the genus) × 100/total number of samples collected

Density (MD): Number of nematode specimens of the genus counted in all samples/total number of the samples collected.

Relative density (RD%): Mean density of the genus × 100/sum of mean density of all nematode genera.

Mean biomass (MB) µg: (Biomass of one nematode individual of the genus) × (absolute density of the genus).

Relative biomass (RMB) µg: (Mean biomass of the genus) × (100)/sum of biomass of all genera).

The following indices were calculated:

Shannon's diversity (H′) = −Σ (*pi* ln *pi*)

Maturity Index (MI)

$$MI = \sum_{i=1}^{n} Vi(i).f(i)$$

Where Vi= cp value of the ith taxon.

　　　f(i) the frequency of that taxon in a sample

* Maturity index (MI) is calculated as the weighted mean of the individual cp value.

Plant Parasitic index (PPI)

PPI = Σ PPiXi / Σ Xi

Where, PPi = PP value assigned to taxon i according to Bongers (1990).

Xi = abundance of taxon i in the sample.

Nematode Channel Ratio (NCR)

NCR = B/B+F

Where, B = Total abundance of Bacterial feeding nematodes

F = Total abundance of Fungal feeding nematodes.

Trophic Diversity index (TDI) = 1 / Σpi²

where pi is the proportional contribution of ith trophic group.

Basal Index = 100xb/b+s+e

Enrichment Index (EI) = 100 x *e/(e + b)*.

Structure Index (SI) = 100x *s/(s + b)*.

where *e*, *b* and *s* are sum products of assigned weights and abundance of individuals in the corresponding *c-p* classes.

RESULTS AND DISCUSSION
Organic enriched habitats
Diversity and abundance

A total of fifty-six nematode species belonging to 10 orders and 30 families were identified. A minimum of ten and a maximum of eighteen species per sample were recorded, with most of the samples containing ten-fifteen species. In terms of individual abundance, the numbers of nematodes in a sample ranged from 350-1842 individuals with mean a value of 1296.93±148.36 per 100 cc of soil. In terms of taxonomic groups (Table.2: Fig.1. AandB), Order Rhabditida was found to be the most prevalent (46%) followed Dorylaimida (21%), Tylenchida (9%), Plectida (7%), Aphelenchida and Mononchida with (4% each), Enoplida (3%), Chromodorida, Monhysterida and Triplonchida with (2% each) occurrence rate. In terms of abundance also, Order Rhabditida was most dominant group (55%), followed by Dorylaimida (19%), Tylenchida (9%), Plectida (6%), Enoplida and Mononchida (3% each), Aphelenchida (2%), Chromodorida, Monhysterida and Triplonchida with (1% each) occurrence rate (Fig.1. A-B).

Trophic groups

The trophic structure of the organic enriched habitats represented by the nematode categories of bacterivores, carnivores (predators), herbivores, omnivores and fungivores. Of the different trophic groups the bacteriovores representing the highest number (50%) followed by predators (23%), fungivores (11%), herbivores (9%) and omnivores shows the least (7%) occurrence rate. In terms of individual abundance too, bacteriovores constituted the most dominant group (54%) followed by predators (18%), fungivores (12%). Representation of herbivores and omnivores were the least with (8% each) occurrence rate (Fig.2. A-B).

Frequency

Among bacteriovores, the highest frequency was recorded for *Chiloplacus subtenuis* (N =44) with an absolute frequency of 73.33%. The species *Neotylocephalus annonae* was the least frequent (N =4) with AF = 6.67 %. Among predators, the species *Aporcelaimellus tropicus* was the most prevalent (N =20) with absolute frequency (AF) of 33.33%, whereas the least frequent species was *Myctolaimus* sp. with (N=2) and AF = 3.33 %. *Aphelenchus avenae* was the most frequent species among fungivores representing (N =28) with absolute frequency (AF) of 46.67% while the *Leptonchus baccatus* (N =7) was the least frequent species among fungivores with AF = 11.67 %. Among plant parasitic or herbivores, *Helicotylenchus dihystera* was the most prevalent with (N = 20) and AF = 33.33 %. The least occurring was *Tylenchus arcuatus* with (N = 5) and AF = 8.33 %. The species *Mesodorylaimus subtiloides* (N = 16) and AF = 26.67 % occurred frequently among omnivores whereas *Thornenema mauritianum* (N = 4) and AF = 6.66% was the least frequent among omnivores (Table 1).

Density

Acrobeloides nanus was the most dominant species (MD = 58.87) among bacteriovores, with relative density of 8.54%. The least dominant species were *Tylocephalus* sp. (MD = 1.99) with relative density of 0.29%, *Neotylocephalus annonae* (MD = 0.99) with relative density of 0.14%. *Discolaimus major* (MD = 19.26) dominated among predators with relative density of 2.79% while *Neoactinolaimus agilis* (MD = 0.65) with relative density of 0.09% was the least among the group. Among fungivores, *Aphelenchus avenae* (MD = 30.05) dominated the group with relative density of 4.36% whereas the representation of *Leptonchus baccatus* (MD = 1.99) was the least with relative density of 0.29%. *Helicotylenchus dihystera* (MD = 14.01) was the dominated among herbivores with relative density of 2.03% while *Tylenchus arcuatus* (MD = 1.8 6) was the least occured with relative density of 0.27%. Among omnivores *Mesodorylaimus subtiloides* (MD = 9.98) dominated the omnivores group with relative density of 1.45% and *Thornenema mauritianum* (MD = 1.35) least frequent with relative density of 0.20% (Table 1).

Table 1. Population structure of soil inhabiting nematodes genera/species in organic enriched environment.

Genera/species	N	AF%	MD	RD%	MB	RMB %
BACTERIOVORES						
Achromadora indica	14.00	23.33	9.45	1.37	15.39	0.89
Anaplectus granulosus	5.00	8.33	1.34	0.19	20.90	1.21
Acrobeles complexus	38.00	63.33	28.14	4.08	20.43	1.19
Acrobeloides nanus	42.00	70.00	58.87	8.54	21.86	1.27
Alaimus primitivus	6.00	10.00	3.26	0.47	15.32	0.89
Caenorhabditis brenneri	21.00	35.00	11.37	1.65	19.16	1.11
Cephaloboides curvicaudatus	25.00	41.67	13.76	2.00	20.14	1.17
Cephaloboides anisospiculus	18.00	30.00	11.05	1.60	24.31	1.41
Cephalobus persegnis	32.00	53.33	38.95	5.65	25.56	1.48
Cervidellus vexilliger	16.00	26.67	18.95	2.75	6.39	0.37
Chiloplacus subtenuis	44.00	73.33	37.07	5.38	20.22	1.17
Diploscapter coronatus	18.00	30.00	25.99	3.77	7.79	0.45
Eucephalobus oxyuroides	20.00	33.33	26.76	3.88	20.07	1.16
Mesorhabditis cranganorensis	30.00	50.00	40.65	5.90	28.45	1.65
Metarhabditis amsactae	25.00	41.67	12.32	1.79	21.28	1.24
Monhystera paludicola	8.00	13.33	7.99	1.16	26.367	1.53
Neotylocephalus annonae	4.00	6.67	0.99	0.14	0.89	0.05
Oscheius shamimi	18.00	30.00	11.49	1.67	28.34	1.64
Panagrolaimus filiformis	35.00	58.33	16.79	2.44	11.80	0.68
Panagrolaimus rigidus	28.00	46.67	13.26	1.92	13.92	0.81
Plectus parvus	14.00	23.33	16.56	2.40	10.64	0.62
Poikilolaimus oxycercus	15.00	25.00	8.11	1.18	41.52	2.41
Protorhabditis oxyuroides	15.00	25.00	6.15	0.89	1.96	0.11
Rhabditis terricola	26.00	43.33	10.81	1.57	19.45	1.13
Teratorhabditis synpapillata	25.00	41.67	7.99	1.16	28.38	1.65
Teratorhabditis andrassyi	18.00	30.00	6.90	1.00	31.05	1.80
Tylocephalus palmatus	5.00	8.33	1.99	0.29	1.19	0.07
Zeldia punctata	8.00	13.33	4.45	0.65	21.69	1.26
Sum	573.00	955.00	451.40	65.50	524.57	30.44
Mean	20.46	34.11	16.12	2.34	18.73	1.09
SD	11.17	18.61	13.95	2.02	9.55	0.55
FUNGIVORES						
Aphelenchoides composticola	21.00	35.00	18.85	2.74	3.77	0.22
Aphelenchus avenae	28.00	46.67	30.05	4.36	5.15	0.30
Basirotyleptus basiri	11.00	18.33	6.59	0.96	8.27	0.48
Filenchus microdorus	15.00	25.00	14.34	2.08	3.44	0.20
Leptonchus baccatus	7.00	11.67	1.99	0.29	10.92	0.63
Tylencholaimellus striatus	14.00	23.33	8.85	1.28	15.93	0.92
Sum	96.00	160.00	80.67	11.70	47.48	2.76
Mean	16.00	26.67	13.45	1.95	7.91	0.46
SD	7.48	12.47	10.05	1.46	4.86	0.28
HERBIVORES						
Helicotylenchus dihystera	20	33.33	14.01	2.03	12.19	0.71
Hoplolaimus indicus	16	26.67	9.56	1.39	57.72	3.35
Longidorous elongatus	8	13.33	3.47	0.50	155.37	9.02
Tylenchorhynchus mashhoodi	12	20.00	6.99	1.01	13.63	0.79
Tylenchus arcuatus	5	8.33	1.86	0.27	14.28	0.83
Sum	61	101.67	35.89	5.21	253.19	14.69
Mean	12.2	20.33	7.178	1.04	50.64	2.94
SD	6.02	10.03	4.86	0.70	61.62	3.58
OMNIVORES						
Eudorylaimus silvaticus	12.00	20	6.55	0.95	104.47	6.06
Microdorylaimus parvus	8.00	13.33	5.46	0.79	16.79	0.97
Mesodorylaimus subtiloides	16.00	26.67	9.98	1.45	31.06	1.80

	N	AF	MD	RD	MB	RMB
Thornenema mauritianum	4.00	6.66	1.35	0.20	20.86	1.21
Sum	40.00	66.67	23.34	3.39	173.18	10.05
Mean	10.00	16.67	5.84	0.85	43.30	2.51
SD	5.16	8.61	3.56	0.52	41.22	2.39
PREDATORS						
Aporcelaimellus tropicus	20.00	33.33	16.50	2.39	120.29	6.98
Butlerius butleri	5.00	8.33	2.21	0.32	20.42	1.18
Discolaimoides bulberiferus	9.00	15.00	3.33	0.48	21.09	1.22
Discolaimus major	18.00	30.00	19.26	2.79	193.24	11.21
Ironus dentifurcatus	15.00	25.00	17.45	2.53	82.36	4.78
Laimydorus papillatus	7.00	11.67	2.14	0.31	19.81	1.15
Mononchoides fortidens	12.00	20.00	9.56	1.39	79.83	4.63
Mononchoides composticola	16.00	26.67	10.13	1.47	26.21	1.52
Mylonchulus hawaiiensis	12.00	20.00	6.99	1.01	47.53	2.76
Neoactinolaimus agilis	4.00	6.67	0.65	0.09	24.38	1.41
Oigolaimella longicauda	6.00	10.00	3.14	0.46	31.09	1.80
Myctolaimus sp.	2.00	3.33	1.51	0.22	51.64	3.00
Tripyla glomerans	13.00	21.67	4.46	0.65	7.00	0.41
Sum	139.00	231.67	97.33	14.12	724.88	42.06
Mean	10.69	17.82	7.49	1.09	55.76	3.24
SD	5.68	9.46	6.55	0.95	52.46	3.04

cp scale – Allocation of values on colonizer-persistor scale (Bongers, 1990).
N, frequency; AF, absolute frequency; MD, density; RD, relative density; MB, mean biomass; RMB, relative biomass.

Mean Biomass
The data of the enriched habitats revealed that the biomass of bacteriovores to be the greatest) among all groups *i.e.*, 50%, followed by Predators (43%), fungivores (3%). omnivores and herbivores (2%) each. *Teratorhabditis andrassyi* constituted the highest biomass among bacteriovores, with a mean value of 31.05 µg and relative mean biomass of 1.80%. The least biomass was recorded for *Neotylocephalus annonae* (0.89 µg), with relative mean biomass of 0.05%. Among predators, the species *Discolaimus major* being the large sized and, having a comparatively high density, had the highest mean biomass (193.23 µg) and relative mean biomass of 11.21% while *Tripyla glomerans* due to its small size showed the lowest mean biomass (7.00 µg) and relative mean biomass of 0.41%. Among fungal feeding nematodes, *Tylencholaimellus striatus*, constituted the highest mean biomass (15.93 µg) and had a relative mean biomass of 0.92%. While, *Filenchus microdorus* (3.19 µg, RMB = 0.20) had the least mean biomass in this group. Although *Helicotylenchus dihystera* was the most dominant species in the herbivore group, *Longidorous elongatus* being large-sized, had the highest mean biomass (155.37 µg) and a relative mean biomass of 9.02%. *Helicotylenchus dihystera* due to its small size had the least mean biomass (12.19 µg) with a relative mean biomass of 0.71%. The species *Eudorylaimus silvaticus* due to its large sized showed a comparatively high density, had the highest mean

biomass (104.47 µg) and relative mean biomass of 6.06% in the omnivore group, while the species *Microdorylaimus parvus* due to its small body size (16.79 µg, RMB = 0.97) had the least mean biomass (Table 1).

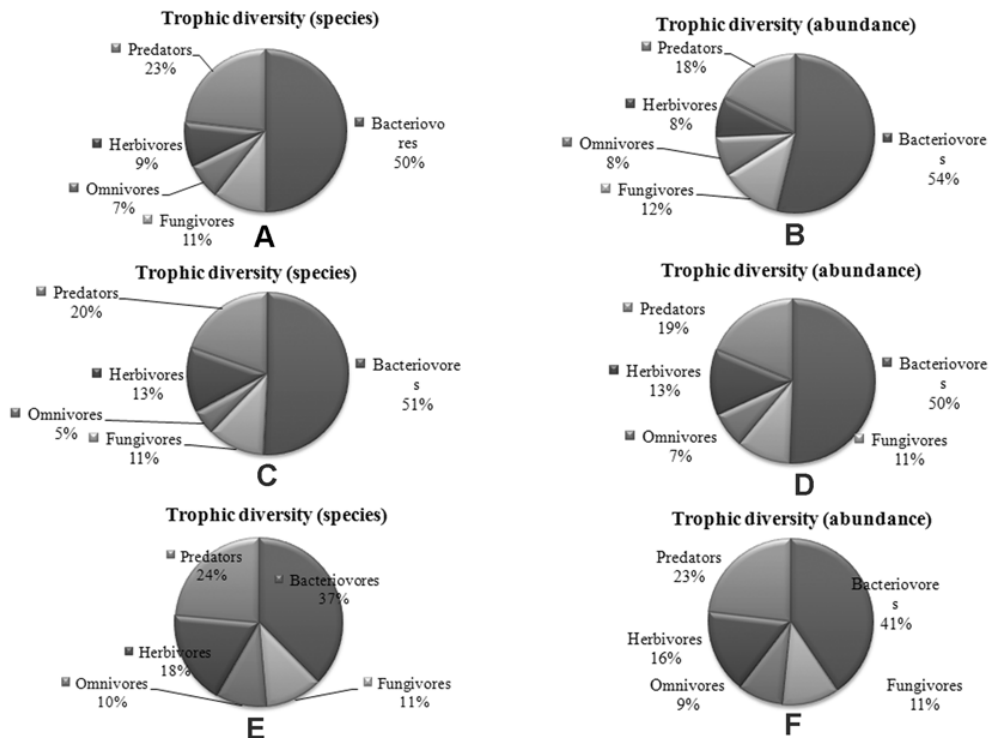**Inorganic enriched habitats**
Diversity and abundance
A total of sixty-one nematode species belonging to 10 orders and 33 families were identified. A minimum of ten and a maximum of twenty species per sample were recorded, with most of the samples containing ten-fifteen genera. In terms of individual abundance, the numbers of nematodes in a sample ranged from 458-1242 specimens with mean a value of 896.93±248.36 per 100 cc of soil. In terms of taxonomic groups, order Rhabditida was found to be the most prevalent (36%) followed Dorylaimida (17%), Tylenchida (15%), Plectida (10%), Monhysterida and Triplonchida with (5% each), Aphelenchida, Chromodorida, Enoplida and Mononchida with (3% each) occurrence rate. In terms of abundance also, Order Rhabditida was most dominant group (42%), followed by Dorylaimida (18%), Tylenchida (16%), Plectida (9%), Monhysterida, Triplonchida and Mononchida (3% each), Aphelenchida (2%), Chromodorida and Enoplida with (2% each) occurrence rate (Fig.1. C-D).

Figure 1. Ordinal Diversity
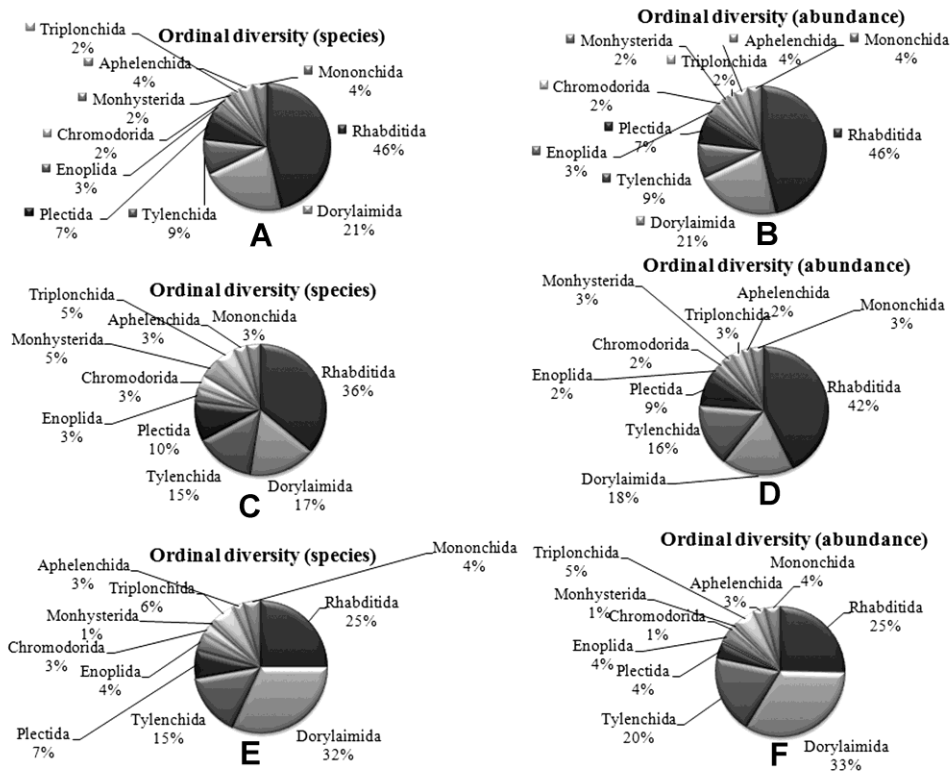
*Ordinal diversity of soil inhabiting nematodes in A-B: Organic enriched habitats; C-D: Inorganic enriched habitats; E-F: undisturbed habitats.

Figure 2. Trophic Diversity

*Trophic diversity of soil inhabiting nematodes in A-B: Organic enriched habitats; C-D: Inorganic enriched habitats; E-F: undisturbed habitats.

Trophic groups

The trophic structure of the inorganic enriched habitats represented by the nematode categories of bacterivores, carnivores (predators), herbivores, omnivores and fungivores. Of the different trophic groups, the bacteriovores represented the highest number of species (51%) followed by predators (20%), herbivores (13%), fungivores (11%), and omnivores were the least with (5%) occurrence rate. In terms of individual abundance too, bacteriovores constituted the most dominant group (50%) followed by predators (19%), herbivores (13%) Representation of fungivores (11%) and omnivores were the least with (7%) occurrence rate (Fig.2. C-D).

Frequency

Among bacteriovores, the highest frequency was recorded for *Cephalobus parvus* (N = 40) with an absolute frequency of 66.67%. The species *Ceratoplectus armatus* was the least frequent (N =4) with AF = 6.33 %. Among predators, the species *Discolaimus similis* was the most prevalent (N =20) with absolute frequency (AF) of 33.33%, whereas the least frequent species were *Fictor vorax* and *Paractinolaimus macrolaimus* with (N = 5) and AF = 8.33 %. *Aphelenchoides composticola* was the most frequent species among fungivores representing (N =22) with absolute frequency (AF) of 36.67% while the *Tyleptus projectus* (N =6) was the least frequent species among fungivores with AF = 10%. Among plant parasitic or herbivores species *Hemicriconemoides magniferae* was the most prevalent with (N = 28) and AF = 46.67 %. The least occurring was *Longidorus brevicaudatus* with (N = 5) and AF = 8.33 %. The species *Moshajia idiophora* (N = 18) and AF = 30.00% occurred frequently among omnivores whereas *Dorylaimus stagnalis* (N = 5) and AF = 8.33% was the least frequent among omnivores (Table 2).

Density

Cephalobus parvus was the most dominant species (MD = 30.60) among bacteriovores, with relative density of 6.53%. The least dominant species was *Wilsonema bangaloreiensis* (MD = 0.82) with relative density of 0.18%. *Aporcelaimellus tropicus* (MD = 15.10) dominated among predators with relative density of 3.22% while *Paractinolaimus macrolaimus* (MD = 0.89) with relative density of 0.19%. Among fungivores, *Aphelenchoides composticola* (MD = 11.76) dominated the group with relative density of 2.51% whereas the representation of *Tyleptus projectus* (MD = 0.98) was the least with relative density of 0.21%. *Tylenchorhynchus mashhoodi* (MD = 9.46) was dominated among herbivores with relative density of 2.02% while *Longidorus brevicaudatus* (MD = 0.99) was the least frequent with relative density of 0.21%. Among omnivores *Moshajia idiophora* (MD = 11.05) dominated the group with relative density of 2.36% and *Dorylaimus stagnalis* (MD = 2.61) was least frequent with relative density of 0.56% (Table 2).

Mean Biomass

The data of the inorganic enriched habitats revealed that the biomass of predators to be the greatest) among all groups *i.e.*, predators (46%), followed by bacteriovores (28%), omnivores (18%) and herbivores (6%) and fungivores (2%). *Acrobeles thornei* constituted the highest biomass among bacteriovores, with a mean value of 43.84 µg and relative mean biomass of 2.83%. The least biomass was recorded for *Udonchus tenuicaudatus* (0.52 µg) with relative mean biomass of 0.03%. Among predators, the species *Discolaimus similis* being the large sized and, having a comparatively high density, had the highest mean biomass (141.80 µg) and relative mean biomass of 7.86% and the least was recorded for *Fictor vorax* (10.93 µg) and relative mean biomass of 0.61%. Among fungivore nematodes, *Ditylencus dipsaci* constituted the highest mean biomass (17.20 µg) and had a relative mean biomass of 0.95% while *Filenchus vulgaris* (1.17 µg, RMB = 0.06) had the least mean biomass in this group. Although *Hemicriconemoides magniferae* was the most dominant species in the herbivore group, *Longidorous brevicaudatus* being large-sized, had the highest mean biomass (70.80 µg) and a relative mean biomass of 3.92%. *Pratylenchus similis* due to its small size had the least mean biomass (1.93 µg) with a relative mean biomass of 0.11%. The species *Dorylaimus stagnalis*is due to its large sized having and having a comparatively high density, had the highest mean biomass (473.25 µg) and relative mean biomass of 26.23% in the omnivore group, while the species *Mesodorylaimus intermedius* (24.77 µg, RMB = 1.37) had the least mean biomass (Table 2).

Undisturbed habitats

Diversity and abundance

A total of seventy-two nematode species belonging to 10 orders and 35 families were identified. A minimum of twelve and a maximum of twenty-three species per sample were recorded, with most of the samples containing twelve-twenty genera. In terms of individual abundance, the numbers of nematodes in a sample ranged from 300-900 specimens with mean a value of 696.93±248.36 per 100 cc of soil were recorded with most of the samples containing 400-700 individuals. In terms of taxonomic groups, order Dorylaimida was found to be the most prevalent (32%) followed Rhabditida (25%), Tylenchida (15%), Plectida (7%), Triplonchida with (6%), Enoplida and Mononchida (4% each), Aphelenchida, Chromodorida, with (3% each) and the least was Monhysterida with (1%) occurrence rate. In terms of abundance also, Order Dorylaimida was most dominant group (33%), followed by Rhabditida (25%), Tylenchida (20%), Triplonchida (5%), Enoplida, Mononchida and Plectida (4% each), Aphelenchida (3%) and the least were represented by Chromodorida and Monhysterida, and (1% each) occurrence rate (Fig.1. E-F).

Trophic groups

The trophic structure of the undisturbed habitats represented by the nematode categories of bacterivores, carnivores (predators), herbivores, omnivores and fungivores. Of the different trophic groups, the bacteriovores represented representing the highest number (37%) followed by predators (24%), herbivores (18%) fungivores (11%), and omnivores shows the (10%) occurrence rate. In terms of individual abundance too, bacteriovores constituted the most dominant group (41%) followed by predators (23%), herbivores (16%). Representation of fungivores (11%) and omnivores were the least with (9%) occurrence rate (Fig.2. E-F).

Table 2. Population structure of soil inhabiting nematodes genera/species in **Inorganic enriched** environment.

Genera/species	N	AF%	MD	RD%	MB	RMB %
BACTERIOVORES						
Achromadora ruricola	15.00	25.00	6.56	1.40	11.02	0.61
Acrobeles thornei	34.00	56.67	28.23	6.03	43.84	2.43
Acrobeloides nanus	32.00	53.33	26.30	5.61	12.82	0.71
Alaimus assamensis	6.00	10.00	2.14	0.46	7.70	0.43
Brevibucca punctata	7.00	11.67	2.84	0.61	18.01	1.00
Ceratoplectus armatus	4.00	6.67	1.04	0.22	2.81	0.16
Cephalobus parvus	40.00	66.67	30.60	6.53	16.07	0.89
Cervidellus vexilliger	15.00	25.00	6.66	1.42	4.26	0.24
Chiloplacus subtenuis	33.00	55.00	27.01	5.76	36.34	2.01
Chronogaster neotypica	18.00	30.00	10.61	2.26	13.09	0.73
Diploscapter indicus	16.00	26.67	7.41	1.58	1.67	0.09
Drilocephalobus alykhani	4.00	6.67	0.98	0.21	1.47	0.08
Eucephalobus striatus	30.00	50.00	19.64	4.19	11.00	0.61
Geomonhystera glandulata	8.00	13.33	3.42	0.73	7.95	0.44
Heterocephalobellus magnificus	10.00	16.67	7.86	1.68	10.85	0.60
Mesorhabditis cranganorensis	36.00	60.00	29.32	6.26	5.86	0.32
Monhystera paludicola	12.00	20.00	5.89	1.26	11.49	0.64
Monhystrella gracilis	15.00	25.00	6.64	1.42	2.92	0.16
Nothacrobeles maximus	7.00	11.67	2.42	0.52	14.52	0.80
Oscheius tipulae	20.00	33.33	9.56	2.04	16.06	0.89
Panagrolaimus hygrophilus	16.00	26.67	8.18	1.75	6.14	0.34
Panagrellus redivivus	15.00	25.00	5.22	1.11	10.86	0.60
Plectus parvus	27.00	45.00	14.17	3.02	4.72	0.26
Plectus parietinus	24.00	40.00	8.56	1.83	1.71	0.09
Prismatolaimus intermedius	20.00	33.33	7.23	1.54	3.90	0.22
Rhabdolaimus terrestris	17.00	28.33	3.26	0.70	1.04	0.06
Stegellata jaisalmerensis	7.00	11.67	1.11	0.24	1.62	0.09
Teratorhabditis synpapillata	16.00	26.67	6.66	1.42	36.96	2.05
Udonchus tenuicaudatus	9.00	15.00	1.11	0.24	0.52	0.03
Wilsonema bangaloreiensis	5.00	8.33	0.82	0.18	0.79	0.04
Zeldia punctata	6.00	10.00	1.16	0.25	8.58	0.48
Sum	524.00	873.33	292.61	62.45	326.58	18.10
Mean	16.90	28.17	9.44	2.01	10.53	0.58
SD	10.42	17.37	9.38	2.00	10.83	0.60
FUNGIVORES						
Aphelenchoides composticola	22.00	36.67	11.76	2.51	2.57	0.14
Aphelenchus avenae	17.00	28.33	6.45	1.38	1.82	0.10
Ditylencus dipsaci	10.00	16.67	4.41	0.94	17.20	0.95
Filenchus vulgaris	13.00	21.67	4.21	0.90	1.17	0.06
Leptonchus buccatus	7.00	11.67	2.16	0.46	11.85	0.66
Tylencholaimus ibericus	13.00	21.67	5.14	1.10	8.78	0.49
Tyleptus projectus	6.00	10.00	0.98	0.21	4.51	0.25
Sum	88.00	146.67	35.11	7.49	47.89	2.65
Mean	12.57	20.95	5.02	1.07	6.84	0.38
SD	5.62	9.37	3.49	0.74	6.02	0.33
HERBIVORES						
Helicotylenchus dihystera	12.00	20.00	8.86	1.89	12.85	0.71
Hemicriconemoides magniferae	28.00	46.67	7.96	1.70	4.61	0.26

Hemicyclophora dhirendri	20.00	33.33	5.11	1.09	4.45	0.25
Hoplolaimus galeatus	14.00	23.33	6.13	1.31	27.59	1.53
Pratylenchus similis	8.00	13.33	2.14	0.46	1.93	0.11
Tylenchorhynchus mashhoodi	14.00	23.33	9.46	2.02	15.81	0.88
Tylenchus agricola	8.00	13.33	1.15	0.25	5.87	0.33
Longidorus brevicaudatus	5.00	8.33	0.99	0.21	70.80	3.92
Sum	109.00	181.67	41.80	8.92	143.89	7.97
Mean	13.63	22.71	5.23	1.12	17.99	1.00
SD	7.44	12.41	3.45	0.74	22.93	1.27
OMNIVORES						
Dorylaimus stagnalis	5.00	8.33	2.61	0.56	473.25	26.23
Mesodorylaimus intermedius	15.00	25.00	6.45	1.38	24.77	1.37
Moshajia idiophora	18.00	30.00	11.05	2.36	38.31	2.12
Sum	38.00	63.33	20.11	4.29	536.32	29.72
Mean	12.67	21.11	6.70	1.43	599.39	33.22
SD	6.81	11.34	4.23	0.90	1174.02	65.06
PREDATORS						
Acrostichus nudicapitatus	12.00	20.00	8.46	1.81	17.77	0.98
Aporcelaimellus tropicus	18.00	30.00	15.10	3.22	122.31	6.78
Brevitobrilus glandulatus	12.00	20.00	5.11	1.09	41.14	2.28
Diplogastrellus sikorai	7.00	11.67	4.12	0.88	17.30	0.96
Discolaimus similis	20.00	33.33	12.12	2.59	141.80	7.86
Fictor vorax	5.00	8.33	3.14	0.67	10.93	0.61
Iotonchus indicus	10.00	16.67	4.36	0.93	106.73	5.91
Ironus longicaudatus	16.00	26.67	8.89	1.90	45.01	2.49
Mononchoides fortidens	10.00	16.67	6.56	1.40	70.85	3.93
Mononchus aquaticus	6.00	10.00	1.45	0.31	18.13	1.00
Paractinolaimus macrolaimus	5.00	8.33	0.89	0.19	26.17	1.45
Tobrilus longus	20.00	33.33	8.69	1.85	131.65	7.30
Sum	141.00	235.00	78.89	16.84	749.78	41.55
Mean	11.75	19.58	6.57	1.40	62.48	3.46
SD	5.61	9.35	4.27	0.91	49.94	2.77

Frequency

Among bacteriovores, the highest frequency was recorded for *Acrobeles complexus* (N = 40) with an absolute frequency of 66.67%. The species *Macrolaimellus iucundus*, *Tylocephalus primitivus* and *Udonchus tenuicaudatus* were the least frequent (N =3 with AF = 5.00 % each). Among predators, the species *Discolaimus major* was the most prevalent (N =19) with absolute frequency (AF) of 31.67%, whereas the least frequent species were *Miconchus digiturus* and *Nygolaimus harislii* with (N = 4 and AF = 6.67 % each). *Aphelenchus avenae* was the most frequent species among fungivores representing (N = 23) with absolute frequency (AF) of 38.33% while *Tantunema intermedium* (N =7) was the least frequent species among fungivores with AF=11.67%. Among plant parasitic or herbivores *Helicotylenchus dihystera* was the most prevalent with (N = 20) and AF = 33.33 %. The least occurring species were *Psilenchus hilarulus* and *Trichodorus complexus* with (N = 4) and AF = 6.67 % each. The species *Eudorylaimus carteri* (N = 16) and AF = 26.67% occurred frequently among omnivores whereas *Thonus cylindricus* (N = 3) and AF = 5.00% was the least frequent among omnivores (Table 3).

Density

Acrobeles complexus was the most dominant species (MD = 27.45) among bacteriovores, with relative density of 6.18%. The least dominant species were *Macrolaimellus iucundus Tylocephalus primitivus* and *Udonchus tenuicaudatus* with (MD = 0.90), (MD = 0.92), (MD = 0.92) and relative density of 0.20%, 0.21% and 0.21% respectively. *Discolaimus major* (MD = 15.61) dominated predators with relative density of 3.51% while *Nygolaimus harislii* (MD = 1.01), with relative density of 2.30% was least frequent among the group. Among fungivores, *Aphelenchus avenae* (MD = 10.22) dominated the group with relative density of 2.30% whereas the representation of *Tantunema intermedium* (MD = 1.41) was the least with relative density of 0.32%. *Helicotylenchus dihystera* (MD = 9.14) dominated among herbivores, with relative density of 2.06% while *Trichodorus complexus* (MD = 0.94) was the least frequent with relative density of 0.21%. Among omnivores, *Moshajia idiofora* (MD = 9.11) dominated the group with relative density of 2.05% and *Thonus cylindricus* (MD = 0.75) least frequent with relative density of 0.17% (Table 3).

Mean Biomass

The data of the undisturbed habitats revealed that the biomass of predators to be the greatest among all groups *i.e.*, Predators (47%), followed by bacteriovores (21%), omnivores (15%) and herbivores (13%) and fungivores (4%). *Poikilolaimus jodhpurensis* constituted the highest biomass among bacteriovores, with a mean value of (57.97 μg) and relative mean biomass of 2.60%. The least biomass was recorded for *Tylocephalus primitivus* (0.92 μg), with relative mean biomass of 0.04%. Among predators, *Discolaimus major* was most frequent but the species *Aporcelaimellus heynsi* being the large sized had the highest mean biomass (211.65 μg) and relative mean biomass of 9.49% and the least was recorded for *Nygolaimus harislii* (14.85 μg) and relative mean biomass of 0.67%. Among fungal feeding nematodes, *Dorylaimellus indicus* constituted the highest mean biomass (39.66 μg) and had a relative mean biomass of 1.78% while *Aglenchus agricola* (2.24 μg, RMB = 0.10) had the least mean biomass in this group. Although *Helicotylenchus dihystera* was the most dominant species in the herbivore group, *Longidorus elongates*

being large-sized, had the highest mean biomass (169.49 μg) and a relative mean biomass of 7.60%. *Basiria abberans* due to its small size had the least mean biomass (2.95 μg) with a relative mean biomass of 0.13%. The species *Eudorylaimus carteri* being large sized and having a comparatively high density, had the highest mean biomass (131.83 μg) and relative mean biomass of 5.91% in the omnivore group, while the *Amphidorylaimus flagellicauda* (4.95 μg, RMB = 0.22) had the least mean biomass (Table 3).

Nematode community dynamics in organic enriched, inorganic enriched and undisturbed habitats

For assessing the community dynamics and indicative role of nematodes in different terrestrial habitats various indices such as Shannon's diversity index (H'), Maturity index (MI) including plant parasitic families (PPI), Maturity index 2-5, Plant parasitic index (PPI), Trophic Diversity Index (TDI), Channel Index (CI), Nematode channel ratio (NCR), Enrichment Index (EI), Structure Index (SI) and Basal Index (BI) were calculated (Table 5; Fig.3).

Table 3. Population structure of soil inhabiting nematodes genera/species in **Undisturbed** environment.

Genera/species	N	AF%	MD	RD%	MB	RMB %
BACTERIOVORES						
Achromadora indica	10.00	16.67	3.56	0.80	8.12	0.36
Acrobeles complexus	40.00	66.67	27.45	6.18	6.59	0.30
Acrobeles cylindricus	25.00	41.67	15.60	3.51	4.49	0.20
Acrobeloides nanus	34.00	56.67	19.99	4.50	9.17	0.41
Acrobelophis minimus	15.00	25.00	5.69	1.28	1.82	0.08
Alaimus primitivus	16.00	26.67	6.12	1.38	6.20	0.28
Amphidelus sylvaticus	11.00	18.33	3.78	0.85	7.22	0.32
Cephalobus persegnis	26.00	43.33	15.21	3.42	8.42	0.38
Cervidellus vex	18.00	30.00	6.21	1.40	8.49	0.38
Chiloplacus symmetricus	38.00	63.33	24.31	5.47	43.37	1.94
Chronogaster typica	12.00	20.00	3.54	0.80	6.90	0.31
Diploscapter coronatus	6.00	10.00	4.13	0.93	3.72	0.17
Eucephalobus striatus	20.00	33.33	14.34	3.23	12.05	0.54
Macrolaimellus iucundus	3.00	5.00	0.90	0.20	2.16	0.10
Mesorhabditis vernalis	28.00	46.67	21.36	4.81	11.44	0.51
Metarhabditis amsactae	12.00	20.00	5.98	1.35	21.53	0.97
Monhystera rolandi	8.00	13.33	3.69	0.83	11.35	0.51
Oscheius zarinae	15.00	25.00	8.96	2.02	23.65	1.06
Panagrolaimus filiformis	20.00	33.33	13.36	3.01	8.42	0.38
Pelodera aligarhensis	7.00	11.67	2.42	0.54	23.02	1.03
Plectus parvus	16.00	26.67	8.96	2.02	2.69	0.12
Poikilolaimus jodhpurensis	10.00	16.67	3.21	0.72	57.97	2.60
Prismatolaimus intermedius	14.00	23.33	4.30	0.97	3.32	0.15
Rhabdolaimus terrestris	4.00	6.67	0.84	0.19	1.13	0.05
Tylocephalus primitivus	3.00	5.00	0.92	0.21	0.92	0.04
Udonchus tenuicaudatus	3.00	5.00	0.92	0.21	1.29	0.06
Zeldia punctata	7.00	11.67	2.21	0.50	14.02	0.63
Sum	421.00	701.67	227.96	51.30	309.46	13.88
Mean	15.59	25.99	8.44	1.90	11.46	0.51
SD	9.21	15.34	6.83	1.54	14.49	0.65
FUNGIVORES						
Aglenchus agricola	11.00	18.33	4.56	1.03	2.24	0.10
Aphelenchoides composticola	17.00	28.33	8.69	1.96	2.45	0.11

|					
Aphelenchus avenae	23.00	38.33	10.22	2.30	2.40	0.11
Dorylaimoides bulbosus	14.00	23.33	5.96	1.34	25.80	1.16
Dorylaimellus indicus	12.00	20.00	6.61	1.49	39.66	1.78
Leptonchus granulosus	9.00	15.00	1.98	0.45	6.07	0.27
Tantunema intermedium	7.00	11.67	1.41	0.32	4.11	0.18
Tylencholaimellus projectus	15.00	25.00	6.54	1.47	11.51	0.52
Sum	108.00	180.00	45.97	10.35	94.24	4.23
Mean	13.50	22.50	5.75	1.29	11.78	0.53
SD	5.01	8.36	3.04	0.68	13.79	0.62
HERBIVORES						
Basiria abberans	6.00	10.00	2.11	0.47	2.95	0.13
Criconemoides informis	9.00	15.00	3.15	0.71	15.96	0.72
Hemicriconemoides magniferae	10.00	16.67	7.92	1.78	13.31	0.60
Helicotylenchus dihystera	20.00	33.33	9.14	2.06	7.95	0.36
Hoplolaimus indicus	14.00	23.33	6.66	1.50	28.83	1.29
Longidorus elongatus	9.00	15.00	3.96	0.89	169.49	7.60
Merlinius brevidens	7.00	11.67	2.54	0.57	3.70	0.17
Pratylenchus penetrans	5.00	8.33	1.89	0.43	7.26	0.33
Psilenchus hilarulus	4.00	6.67	1.01	0.23	8.48	0.38
Trichodorus complexus	4.00	6.67	0.94	0.21	7.47	0.34
Tylenchorhynchus striatus	17.00	28.33	5.45	1.23	4.23	0.19
Tylenchus arcuatus	11.00	18.33	4.21	0.95	8.96	0.40
Xiphinema brevicollum	15.00	25.00	5.11	1.15	53.35	2.39
Sum	131.00	218.33	54.09	12.17	331.94	14.88
Mean	10.08	16.79	4.16	0.94	25.53	1.14
SD	5.12	8.54	2.60	0.58	45.39	2.04
OMNIVORES						
Amphidorylaimus flagellicauda	7.00	11.67	1.99	0.45	4.95	0.22
Eudorylaimus carteri	16.00	26.67	7.56	1.70	131.83	5.91
Mesodorylaimus bastiani	11.00	18.33	3.21	0.72	19.26	0.86
Moshajia idiofora	13.00	21.67	9.11	2.05	83.25	3.73
Opisthodorylaimus maqsoodi	6.00	10.00	1.42	0.32	23.29	1.04
Oriverutus hastus	9.00	15.00	3.45	0.78	16.10	0.72
Thonus cylindricus	3.00	5.00	0.75	0.17	44.40	1.99
Sum	65.00	108.33	27.49	6.19	323.07	14.49
Mean	9.29	15.48	3.93	0.88	46.15	2.07
SD	4.42	7.37	3.19	0.72	45.77	2.05
PREDATORS						
Actinolaimus armatus	6.00	10.00	2.98	0.67	45.89	2.06
Aporcelaimellus heynsi	15.00	25.00	14.11	3.18	211.65	9.49
Aquatides intermedius	5.00	8.33	1.89	0.43	61.92	2.78
Butlerius butleri	5.00	8.33	2.98	0.67	27.54	1.23
Discolaimium dubium	6.00	10.00	3.02	0.68	22.65	1.02
Discolaimus major	19.00	31.67	15.61	3.51	155.28	6.96
Ironus dentifurcatus	13.00	21.67	8.44	1.90	45.97	2.06
Laimydorus siddiqii	7.00	11.67	3.14	0.71	107.93	4.84
Labronema neodiversum	9.00	15.00	4.96	1.12	69.77	3.13
Lordellonmena indicum	8.00	13.33	4.11	0.92	26.20	1.17
Makatinus heynsi	11.00	18.33	4.22	0.95	84.02	3.77
Miconchus digiturus	4.00	6.67	1.11	0.25	33.97	1.52
Mononchus truncatus	7.00	11.67	2.98	0.67	48.28	2.16
Mylonchulus brachyuris	10.00	16.67	7.97	1.79	69.34	3.11
Nygolaimus harislii	4.00	6.67	1.01	0.23	14.85	0.67
Oigolaimella longicauda	5.00	8.33	2.45	0.55	29.11	1.31
Tobrilus gracilis	7.00	11.67	6.01	1.35	100.97	4.53
Trischistoma pellucidum	5.00	8.33	1.86	0.42	16.29	0.73
Sum	146.00	243.33	88.85	20.00	1171.60	52.53
Mean	8.11	13.52	4.94	1.11	65.09	2.92
SD	4.11	6.86	4.17	0.94	52.05	2.33

Weighted faunal analysis
Food web diagnostics of three different habitats were compared in terms of Enrichment index (EI), Structure index (SI) and Basal index (BI) following the weighed faunal analysis concept of Ferris *et al.* (2001). Organic enriched habitats revealed that most of the values for SI and EI lies in quadrat 'A' and some of the in quadrat 'D' indicating highly enriched, disturbed and unstructured ecosystem with some moderate to low basal conditions. Inorganic enriched habitats data revealed that most of the values for SI and EI lies in quadrat 'D' and 'A' while some values cluster in quadrat 'C' reflecting highly basal and moderate to highly enriched ecosystem. conditions. Undisturbed habitats showed most of the sampling sites indicating high enrichment while few indicated high structured status of the ecosystem (Fig. 4).
Correlations among different variables
The biplot graph (Fig. 5) depicts the correlation of different variables differencing the three different terrestrial habitats.

We did multivariate analysis *viz.,* Principal component analysis (PCA) program to know the relationship between the variables and retrieved a correlation circle (Fig.6), which depicts the correlations among various variables. Structure index showed a positive correlation with fungivores, herbivores, omnivores and predators while negative correlation with bacterivores. Almost all the trophic groups except bacterivores showed a positive relationship with SI, Plant Parasitic Index/PPI, TDI and MI. SI also depicted low positive relationship with CI while negative correlation with NCR. Bacterivores showed positive correlation with EI and BI while rest of trophic group showed a negative correlation with EI and BI. Only bacterivores indicated robust positive correlation with EI in comparison to other trophic groups. EI almost showed no correlation with PPI. The explanation for these correlations would be understood after analyzing the biplot graph.

Figure 3. Ecological Indices
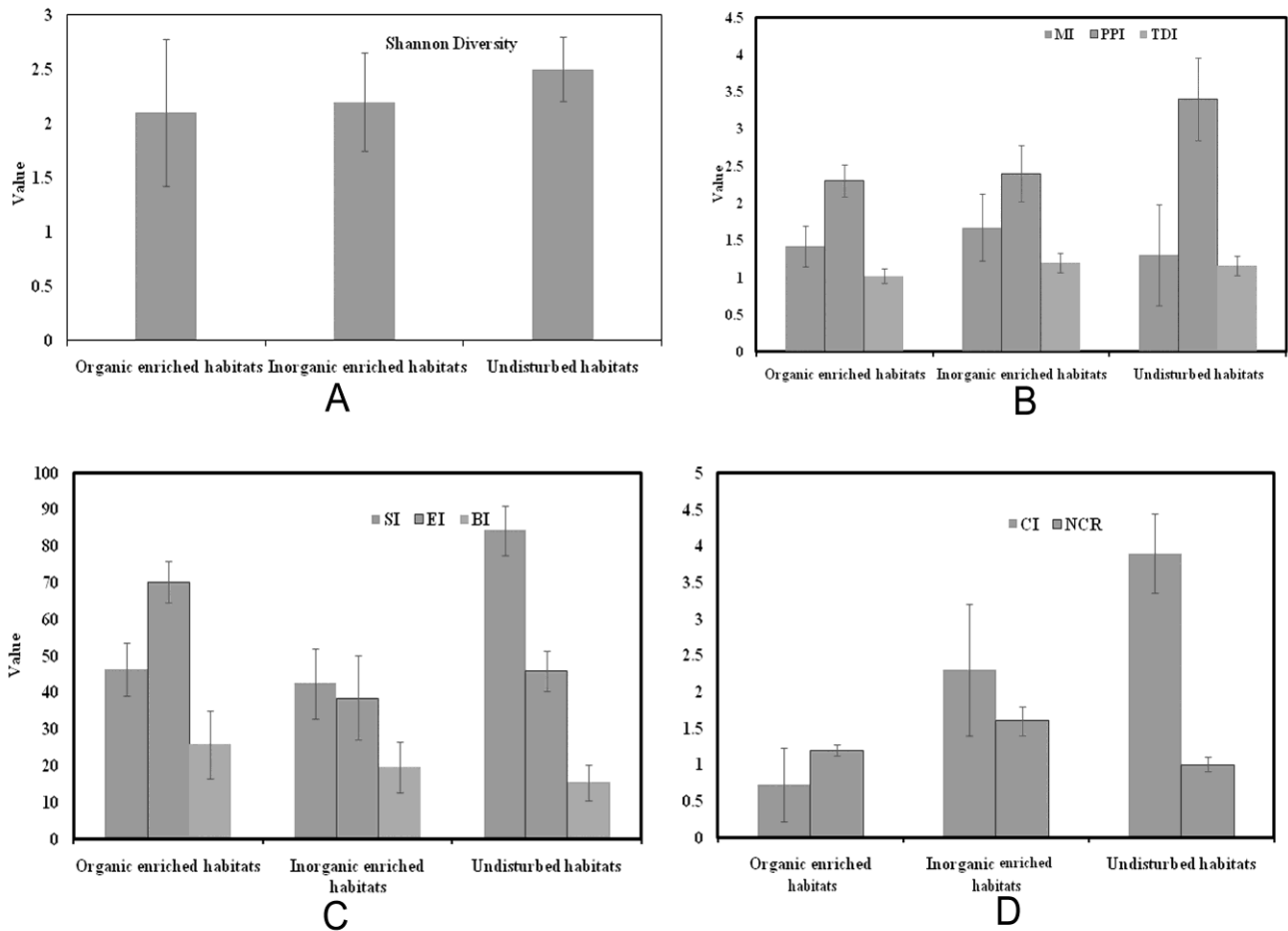
*Relationship and comparison of different diversity and ecological indices in three different habitats: A: Shannon diversity; B: Maturity Index (MI), Plant Parasitic Index (PPI) and Trophic Diversity Index; C: Structure Index (SI), Enrichment Index (EI) and Basal Index (BI); D: Channel Index (CI) and Nematode Channel Ratio (NCR).

Figure 4. Quadrate
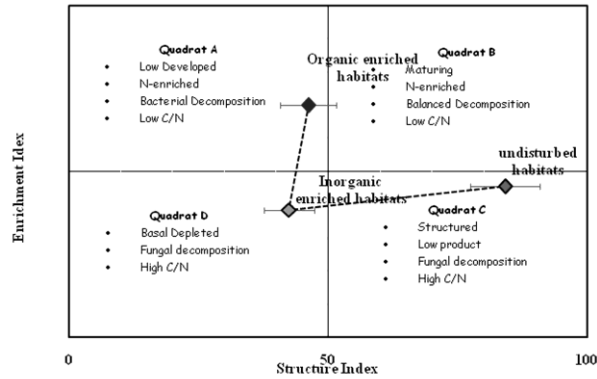
*Quadrat analysis [Graph constructed using functional guild approach, after Ferris (2001)] depicting comparative status and stability of three different habitats.

Figure 5. Biplot
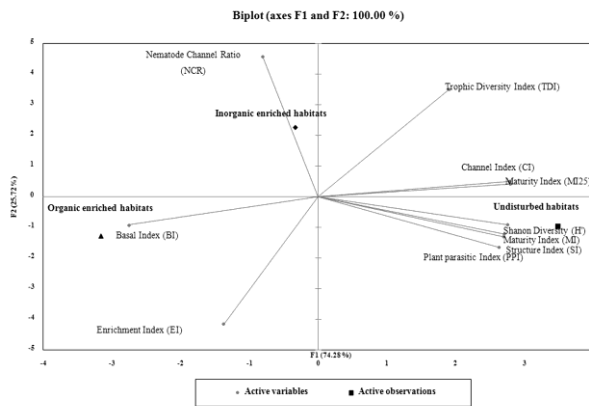
*Biplot ordination (PCA) of observation on trophic group abundance in terms of species, total nematode abundance and various other variables in three different fields.

Figure 6. Correlation circle
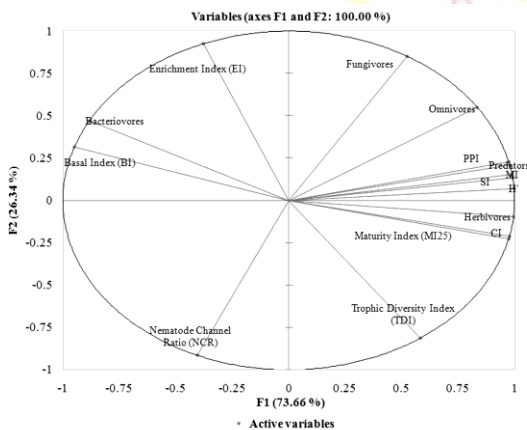
*Biplot correlation circle depicting the correlation between the different variables.

In Biplot ordination, graph the the active variables and active observations clearly give the idea how would the different ecological indices *viz.*, Maturity Index (MI),

Plant parasitic Index (PPI), Channel Index (CI), Basal Index (BI), Maturity Index (MI) Trophic Diversity Index (TDI), Structure Index (SI), Enrichment Index (EI) and Nematode Channel Ratio (NCR) clearly demarcating the three different soil ecological system. The different habitats can be clearly differentiated with respect to different parameters used in the analysis. The angle between the active variables (Ecological indices) and active observation (habitats) may be acute, right or obtuse to the suggesting positive, nil and negative correlation respectively. In the present study, all the three different habitats (Active Observation) can be clearly differentiated with respect to active variables (ecological indices and generic diversity). In natural terrestrial undisturbed habitat, we get the cluster of MI, SI, PPI and H' suggesting these variables are positively correlated and also the habitat is negatively correlated with NCR, BI and EI suggest the negative correlation and would have low values of these indices with respect to all other habitats considered for analysis. In other two active observation (Inorganic Enriched habitat) BI and NCR is Positively correlation suggesting very basal condition and bacterivore decomposition channels operates in Inorganic Enriched habitat) In Organic enriched habitat EI is positively correlated suggesting the highly enriched condition and high number of bacterivores.

Discussion

Soil nematode assemblage and their trophic changes have been found to be one of the best biological tools for assessing soil processes and plant conditions in terrestrial ecosystems (Wang *et al*., 2009; Pen-Mouratov *et al*., 2010). Soil nematode communities represent the most abundant multicellular animal group on earth and are important component of the soil biota (Sohlenius,1980; Bongers and Bongers, 1998). Their communities have the potential to provide unique insights into many aspects of soil processes. Soil nematodes regulate the bacterial and fungal populations and thus are associated with cycling of major nutrients in soils (Ingham *et al*., 1985). Hence there are significant possibilities for the use of nematode populations and diversity as indicators of overall soil condition. Nematode communities are sensitive to chemical and physical disturbances in ecosystem. These disturbances can alter nematode communities in different ways (Fiscus and Neher, 2002). In natural and plantation forest ecosystems, soil nematode communities play important an important role in the functioning of ecosystem (Yeates 2003; Bakonyi *et al*., 2007). In forest ecosystem nematode communities appeared to be more in diverse as they are subjected to changes in food resource availability and environmental conditions Yeates (2007). The nematode diversity of specific type of habitats revealed many characteristics that proves to be useful for use as biological indicators of agricultural practices, soil characteristics, soil types (Sithole *et al*., 2016) and the degree of conservation of soils (Hu *et al*., 2011, 2014; Li *et al*., 2012; Zhang *et al*., 2012; Hu and Qi 2013; Park *et al*., 2013; Ugarte *et al*., 2013).

The present study revealed a great degree of diversity of soil inhabiting nematodes from three different habitats across Western Uttar Pradesh. The generic diversity and abundance of the trophic groups showed substantial variations at three different habitats. The increase in the diversity and abundance of the herbivores in inorganic enriched and undisturbed pristine habitat appeared to be the only significant change. Among the taxonomic groups recorded, the order Rhabditida was the most dominant in terms of individual abundance as well as in generic diversity in all habitats this is in all probability because of the nematodes of order Rhabditida appeared to be adaptable to different types of habitats and thus represented the resulted in such morphological great morphological diversity Jahan and Tahseen (2018). Hence, they can be regarded as highly evolved clades with a great degree of adaptive radiations. These r-selective opportunists indicate towards disturbance and utilize the abundant resources as colonizers to build up their populations.

Fifteen species *viz.*, *Acrobeloides nanus, Acrobeles complexus*, *Cephalobus parvus, Chiloplacus subtenuis, Panagrolaimus filiformis*, *Mesorhabditis vernalis*, *Aphelenchus avenae*, *Aphelenchoides composticola*, *Helicotylenchus dihystera*, *Hemicriconemoides* magniferae, *Mesodorylaimus subtiloides*, *Eudorylaimus carteri*, *Aporcelaimellus tropicus*, *Discolaimus similis*, *Discolaimus major* were frequently found to be most important of the total species identified and constitute about 30.25-51.18% of total nematode community. The high frequency and dominance of these species also indicated their greater competence in variable environment and habitat types and also their cosmopolitan nature. Similar findings were reported by different workers like Eder and Kirchengast, 1982 during the study reported six species out of twenty-two species which made about made up 91% of the total nematode populations. While reported seven of seventy-one nematode species to constitute 71% of total nematode population were studied by Beier and Traunspurger (2003b).

In organic enriched habitats the presence of rhabditids particularly the Rhabditidae, Cephalobidae and Panagrolaimidae is indicative of high enrichment. The presence of *Acrobeloides nanus*, *Chiloplacus subtenuis* are well adapted to depleted conditions of resources and can withstand stress particularly the moisture stress. While the frequently abundance of species *viz.*, *Mesorhabditis vernalis*, *Teratorhabditis synpapillata, Diploscapter coronatus, Butlerius butleri, Oigolaimella longicauda Panagrolaimus filiformis*, in organic enriched field reflected the conditions of low oxygen concentrations. Some other bacterivores *viz.*, *Tylocephalus palmatus*, *Oscheius shamimi*. found in varios samples showed phoretic association with insects that depend on the plants in one way or other.

The inorganic habitat has somewhat stressed condition and the only tolerant nematode group was observed in high numbers *viz.*, *Cephalobus parvus*, *Acrobeles*

thornei, *Chiloplacus subtenuis* and *Acrobeloides nanus*. These findings well confirm with earlier work of Yeates and Bird (1994) and Gomes *et al*. (2003) where it was observed that the cephalobids were the most abundant bacterial feeders present in cropping systems. Cropping fields are mainly characterized by repeated or regular disturbances *viz.*, cultivation, use of organic matter, pesticides and fertilizers and as a result of these types of protuberances decreases of diversity (Yeates and Bongers, 1999) and increases the number and dominance of opportunistic taxa.

The population of dorylaims was highest in undisturbed habitat, followed by rhabditids and least was observed for Monhysterids. The population was highest in undisturbed area due to the abundance of prey and predatory dorylaims. The species that were prevailing in undisturbed ecosystem were *Discolaimus major*, *Aporcelaimellus heynsi*, *Ironus dentifurcatus* and *Makatinus heynsi*. The presence of *Discolaimus major* might be due to it is commonly found or easily availability of food resources, moisture and may be due climatic conditions. A high diversity of dorylaim nematodes reflect less intrusion of various human activities in the field while a low number indicates more protuberances (Neher, 2001; Gomes *et al.*, 2003).

A relatively low proportion of bacterivores can thus indicate undisturbed conditions of the soils studied. In the present study, bacterivores were the most dominant in terms of generic diversity as well as individual abundance among the trophic group recorded from organic enriched habitats and was low in undisturbed habitat.

In undisturbed forest ecosystem population of bacterivore nematodes frequently found most dominated among all trophic groups (Wasilewska, 1979; Háněl, 1997; Yeates *et al.,* 2000) and as any protuberance in the ecosystem occur their abundance increases in soil nematode community (Sohlenius, 2002; Háněl, 2004). At undisturbed habitat, where the vegetation was substantial, in terms of abundance, the diversity of Tylenchida was highest (16%) comparable to other habitats, *i.e.,* inorganic enriched (13%) and organic enriched habitats (8%) in old organic habitat like heap of manure with time leads to the development of vegetation but the soil structure could not be observed in that habitat. In terms of genera, undisturbed habitat has highest percentage of tylenchids (18%) followed by organic habitat (13%) and inorganic rich habitat (9%). In Inorganic habitat although disturbed, the tylenchids were in substantial numbers this may be due to the inorganic nutrient enrichment and development of heterogenous vegetation. And in field that were treated with inorganic fertilizers the overall generic diversity was low. The increase in the trophic diversity of the herbivores was apparently at the expense of predators and omnivores. In both the enriched habitat the diversity of fungivores is significantly less than the bacteriovores but their relative abundance was comparable perhaps representing that

their resource utilization was better or their food source was more varied and plentiful.

Shanon's diversity index (H′) reflects diversity of nematodes in an ecosystem. Higher values of H′ show highly diverse ecosystem while low values show the contrary. Different authors reported variation of H′ value in different habitats including forest area. Háněl (1995) recorded successional variation of H′ value and found that the number of species was lower in the initial successional stages (field, fallow) than in older ones (meadow, forest) and the greatest species and generic diversity (H′) was found in meadow. Pattison *et al.* (2004) recorded H′ value of nematode diversity for banana crop (1.35), pasture (1.97) and forest (2.07). Tahseen *et al.* (2011) also observed higher diversity in forest region. The values of H′ were higher in undisturbed habitat, followed by inorganic rich habitat and the least was observed for organic rich habitats. It can be stated that organic enriched habitat is highly disturbed with high microbial activity and the conditions of high enrichment which showed less structured status of the soil and results in disturbances in soil ecosystem. The Maturity index was highest in the undisturbed area, indicating a more stable nematode community in this habitat than in others. In organic enriched habitat, the species *Acrobeloides nanus* was most abundant with a low c-p value, showing higher population densities as well as dominance in all the three habitats due to high organic accumulation (litter). The substantial litter accumulation in natural forests helps create a humus layer and better structured soil populations. Háněl (1996) and Čerevková and Renčo (2009) also reported that *Acrobeloides* was the predominating genus in undisturbed natural forests. Háněl (2001) also referred to an increasing abundance of *Acrobeloides* due to litter accumulation. The maturity index (MI) was calculated to assess the maturity of the forest ecosystems. MI values for soil subjected to varying levels of disturbance range from >2.0 in nutrient enriched disturbed systems to 4.0 in undisturbed, pristine environment (Bongers and Ferris, 1999).

Food web indices like EI, SI, BI and CI may provide an excellent means for studying the stability of ecosystem, weather it is enriched, structured or stressed and provide information on the dynamics of the soil food web (Ferris *et al.*, 2001). EI is basically known to reflect availability of resources to the soil food web and response of primary decomposers to the resources (Ferris *et al.*, 2004).

In organic enriched habitat the values of EI were highest 70.1±22.7 (30.0-95.7) followed by undisturbed natural forest 52.9±32.6 (17.0-75.4) and was lowest in inorganic enriched habitat 48.50±32.7 (18.0-70.4). The highest value of EI reflects its enrichment. SI represents an aggregation of functional guilds with c-p values ranging from 3-5. SI is primarily determined by omnivores and predatory nematode populations, which are highly sensitive to disturbances and need much more time to establish than opportunistic fungivore and bacteriovore nematodes (Ferris *et al.*, 2001). SI describes whether soil

ecosystem is structured (high SI) or disturbed (low SI). It has been reported in earlier studies that generally in fallow soils and forests, the value of SI is higher which may be due to high abundance of omnivores and predators suggesting a food web with more trophic linkages (Ferris and Matute, 2003). Higher the values of SI, more complex are the community structure. Fallow lands and forests have been reported to be more complex communities with reference to nematode in many studies (Tomar and Ahmad, 2009). The values of SI during present study were highest in undisturbed forest 84.2±8.4 (60.9-98.7) followed by inorganic enriched 54.5±29.3 (17.0-72.9) and organic enriched habitats 46.2-8.9 (15.4-59.2). Ferris *et al.*, 2001; Berkelmans *et al.*, 2003 commented that high values of SI indicated undisturbed conditions of the ecosystems studied. The high values of MI, SI as well as diversity indicated structured nematode assemblages. This implies that a stable food web in soil can be maintained by different species composition of nematodes (Háněl and Čerevková, 2006).

The degree of fungal participation in the primary decomposition channels of soil food webs is suggested by CI. The higher values of CI indicate a fungal dominated decomposition pathway while lower value indicates the bacteria-based decomposition pathway. The values for CI in present study were higher at undisturbed forest 3.9± 0.1 (3.6-4.5) which indicated that greater participation of fungivores in the breakdown of soil organic matter. It is an agreement with Ruess (2003) who stated that high value of CI indicated a fungal based energy channel in coniferous forest sites.

The basal index (BI) is an indicator of a food web diminished by stress or limited nutrient resources (Ferris *et al.*, 2001). The values for BI in present study were higher at inorganic patches 19.6±8.5 (13.7-38.3) followed by organic habitat 25.7±22.9 (18.8-37.8) and undisturbed habitat 15.3±5.6 (12.7-31.3) which indicated that the food web structure was probably fungal dominated in undisturbed forest our result concurred with Berkelmans *et al.* (2003) who stated that high value of BI indicates poor ecosystem health.

Low values of MI and SI and high values of EI, BI and CI in the organic enriched habitat as compared inorganic rich habitat and undisturbed habitat indicated that the soil food web was severely disrupted in that region.

The PPI is very good indicator of plant parasitic nematode resources. It is comparable to MI but computed only for plant parasitic nematodes with a rational that their abundance is determined with the vigour of the host plant, which in turn is determined by system enrichment (Bongers *et al.*, 1997). Larger PPI values indicate low levels of disturbance to the community and are associated with dominance by slow reproducing, disturbance-intolerant 'persister' nematodes (analogous to K strategists). Conversely, smaller PPI values indicate high levels of disturbance and are associated with rapidly reproducing, disturbance tolerant 'colonizer' nematodes (analogous to r

strategists) (Bongers, 1990, 1999). The PPI is very good indicator of plant parasitic nematode resources. The PPI values varies in different fields *viz*., for good crop fields range from 2.3 (Pate *et al*., 2000) to 2.82 (Neher and Campbell, 1994). In waste lands uninterrupted field, the highest PPI values (2.50-3.50) indicated the presence of ample vegetation in these lands which showed undisturbed vegetation in a succession phase. The lowest PPI values for organic enriched field are probably because of limited plant resource and a lack of its variety. The relatively lower PPI of the inorganic enriched fields might be due to fact that some of the samples were collected from fallow soils which were stressed or those supplemented with manure and were disturbed due to various agricultural practices (Ou *et al*., 2005). The highest value in undisturbed habitats indicated that no human intervention and there is more ample vegetation or grasses which are grown when field left fallow or undisturbed.

As per observations of quadrat analysis, it can be said that organic enriched habitats found to highly enriched, disturbed and unstable conditions of the ecosystem. It reflects anthropogenic activities or disturbances in the environment. Inorganic enriched habitats revealed that stress or basal conditions with moderate to high enrichment. It reflects low structure nature and moderate disturbances in the ecosystem due to human activities like various agricultural practices, household discharge of various chemicals and various industry wastes. Undisturbed indicated conditions highly structured stable and undisturbed nature of ecosystem with no human activities or any other disturbances. The system highly matured status of the ecosystem.

Biplot graph and PCA circle revealed the relationship between different variables and differentiated three different terrestrial habitats. Status of the various ecosystem conditions observed and compared on the basis of abundance and presence of different trophic groups of nematodes and their relationship with various diversity and ecological indices.

CONCLUSION

The present work was under taken to study the indicative assessment of nematode in differentiating the terrestrial habitats with respect to soil health using nematode community structure as a marker. Human disturbance can cause unintentional or intentional loss to ecosystems and environment, in particular industries and malpracticed agricultural activity where indiscriminate amount if inorganic fertilizers are used causes huge soil biodiversity degradation, which results in the loss of the structure and health of soil. The study contributes to an increase in the knowledge of diverse nematode community structure in different stressed and undisturbed soils and the changes that they undergo under the influence of different anthropogenic disturbances. These results may help the stakeholders to model and predict changes in biodiversity and species interactions with land use change. Further studies are

required in the field of sampling methods, data analysis and use statistical tool for a better understating of different species of nematodes as bioindicators of soil health.

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