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Original article

Soil ciliates of the Indian Delhi Region: Their community characteristics with emphasis on their ecological implications as sensitive bio-indicators for soil quality

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A B S T R A C T

The present investigation aims to study the diversity of ciliates from different habitats in and around Delhi, India, and the correlation of this diversity with soil quality {agricultural lands (site 1 and 2), dump yards (site 3 and 4), sewage treatment plant (site 5), residential land (site 6), landfill (site 7) and barren land (site 8)}. Various physicochemical parameters of the different soil samples were studied and analysed for soil texture, interstitial water, pH, conductivity, total organic carbon, total organic matter, total nitrogen and phosphorous content, using standard protocols. Seventeen ciliate taxa belonging to four classes, seven orders, ten families, and 17 genera were recorded, with the maximum number of species (eleven) belonging to the class Spirotrichea. Ciliate diversity was highest at sites 5 and 6 and lowest at sites 1 and 2. *Spathidium* sp. was the dominant species in the conditioned land (site 8), while the ciliate *Colpoda* sp. was present in all the sites examined, showing the highest population density in the sewage treatment plant site (site 5). Statistical analysis showed that ciliate diversity was positively correlated to physicochemical parameters such as interstitial water, total organic matter and organic carbon, total nitrogen and total phosphorous content. Analyses of spirotrichs/colpodids (S/C) ratio and diversity indices implied that the habitat conditions of sites 1, 2, 3 and 8 are relatively unfavourable for soil ciliates to flourish; while sites 4, 5, 6 and 7 provided more favourable conditions. The ubiquity of ciliate distribution suggests their important role in the soil food webs and nutrient cycling, and their community structure and specific characteristics appear to be of major importance for soil formation. A full understanding of soil ciliate diversity and physicochemical parameters helps to inform best practice for improving soil quality as well as conservation practices for sustainable development and management of farms and cultivated lands. In conclusion, ciliate diversity serves as an important and sensitive bio-indicator for soil quality.

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1. Introduction

There are countless organisms inhabit the soil because they utilize its elaborate resources of minerals, water, air and organic matter. Thus, soil contains a large proportion of the biodiversity of the earth, with one square metre of soil harbourings more than one thousand species of animals (Anderson and Healey, 1972), and possibly, over a half million species of prokaryotes (Torsvik et al., 1996). Soil protozoa, and ciliates in particular, represent a very important microbial group within the soil community, with both a high abundance and a vital ecological role in respect to nutrient cycling, accelerating the turnover of soil bacterial biomass (Acosta-Mercado and Lynn, 2004), regulating the size and the composition of soil bacterial communities, stimulating ammonification and nitrification (Li et al., 2010a), and significantly enhancing the growth of plants and earthworms (Foissner et al., 2005). Moreover, ciliates play a major role within the soil microbial loop (Azam et al., 1983; Xu et al., 2014) since they regulate the growth of bacteria and other smaller protists, maintaining ecological stability (Clarholm, 1985; de Ruiter et al., 1993; Finlay and Esteban, 1998; Ekelund et al., 2002; Bonkowski, 2004; Li et al., 2005; Esteban et al., 2006; Puitika et al., 2007; Bielewicz et al., 2011; Geisen et al., 2015; Geisen et al., 2018), and can also be regarded as flagship taxa occupying a key position within soil food webs (Foissner, et al., 2002; Foissner, 2005; Chao et al., 2006). Therefore, studies on their dynamics and their community structures should provide us with powerful means for assessing and monitoring changes in the biotic and/or abiotic soil conditions, and many ciliate taxa can be considered as markers of environmental stress in the soil ecosystem (Coppellotti and Matarazzo, 2000; Xu et al., 2011; Debastiani et al., 2016), as well as, for monitoring the major soil pollutants, contaminants and land use transformations (Lüftenegger et al., 1985; Foissner, 1987; Yeates et al., 1991; Foissner, 1999; Mayzlish and Steiberger, 2004).

Unfortunately, most of this important knowledge is still widely ignored by ciliatologists and soil ecologists worldwide in general and in India in particular, possibly because: 1 – many problems in the methodology and taxonomy of these cilioprotists are still considerable; 2 – the ciliate organisms are too minute to be easily recognized and/or studied; 3 – active ciliate cells are in the evolved soils and even under stable conditions are very seldom to be observed, whereas those encysted specimens found can be difficult to identify; and 4 – few specialists are available for soil ciliate identification. Therefore, this work aims to characterize and investigate the relationship between the soil ciliate community and various physicochemical parameters, i.e. the abiotic and biotic factors of the soil ecosystem, through analysing the biodiversity, abundance, dominance, spirotrichs/colpodids (S/C) ratio and similarity of soil ciliate communities at eight different habitats in and around the Delhi region, northern India.

2. Materials and methods

2.1. Study area and sampling sites

Delhi is a massive metropolitan area in northern part of India, and is bordered by the state of Haryana to the north, west and south and Uttar Pradesh (UP) to the east. Samples of soil were collected from eight different sites in and around the Delhi region comprising of agricultural lands (sites 1 and 2), dump sites (sites 3 and 4), a sewage treatment plant site (site 5), residential land (site 6), a landfill site converted to a park (site 7) and conditioned land (site 8) (Fig. 1 & Table 1). Samples were collected from November 2015 to February 2016 and were processed immediately for further analyses. The characteristics of the sampling sites are described as follows:

Site 1: Mahendergarh. The soil samples were collected from fields used for growing crops in the village of Hazipur, which comes under the district Mahendergarh (Haryana). The actual distance between New Delhi and Hazipur is 135 km. The majority of the population of the village is engaged in agriculture. The region is well known for crops such as wheat, mustard, bajra, etc.

Site 2: Bhiwani. The soil samples were collected from fields used for growing crops in Indiwali village which is a part of Bhiwani district in Haryana. It is 133.6 km from New Delhi and 247.9 km far from Chandigarh.

Site 3: Gazipur. Gazipur is a village in the east Delhi district of Delhi state, India. The samples were collected from a municipal sewage dumping ground.

Site 4: Karnal. Karnal is a city located in the Delhi. Soil samples were collected from a site located on Karnal bypass which is also a waste dumping site.

Site 5: Rithala. Sludge samples were collected from a sewage treatment plant located in Rithala, on the rural fringe of North West Delhi.

Site 6: Acharya Narendra Dev College (ANDC). Soil samples were collected from the college campus area, located in Govindpuri, Kalkaji, New Delhi.

Site 7: IP Park. Samples were collected from this park, which is one of the largest in the city of Delhi. It was constructed over a previous landfill site.

Site 8: Govindpuri petrol pump. This is located near Govindpuri metro station. The samples were collected from barren land at the petrol pump.

2.2. Sample analysis

Samples were air dried and the non-flooded petri-dish method was used to process the ciliate samples according Foissner, 1987. About 150 gm of each soil sample was saturated with distilled water in a large petri dish of about 10–15 cm in diameter (Foissner, 1997a). A small amount of water from the flooded petri dishes were withdrawn at intervals of 24, 48 and 72 hr. Ciliate species were identified with the help of bright field and differential interference contrast microscopy, complemented by the protargol staining technique (Wilbert, 1975; Foissner, 1991, 2014). Identification was based on descriptions by Kahl (1935), Corliss (1979), Shen et al. (1990), Foissner (1987, 1993), Berger (1999), Foissner et al. (2002), Lynn and Small (2002) and Lynn (2008). The most probable number method (MPN) was the base for the quantitative analysis of the ciliate taxa in the soil samples and the fluctuation in the number of ciliates was observed on each day (Chen et al., 2009). The physical and chemical parameters of the soil in each samples were determined according to standard procedures, namely: soil texture by the international pipette method, water holding capacity (interstitial water) was determined according to the method given by Estefan et al. (2013), pH by the electrometric method according Bovie (1924), electrical conductivity by the electrometric method, organic carbon/organic matter by the Walkley and Black method (1934), nitrogen content by the alkaline permanganate method (Subbiah and Asija, 1956; Piper, 1966; Oien and Selmer-Olsen, 1980) and phosphorous content by Olsen bicarbonate method (Olsen, 1954).

2.3. Statistical analysis

The dominancy and constancy of ciliate species in each soil habitat were determined according Ma et al., 2008. The S/C (spirotrichs/colpodids) ratio was calculated on the basis of number of spirotrich and colpodid species present at different sites (Foissner et al., 2005). The Shannon-Weiner index, Simpson index and dominance index were used to evaluate the diversity of ciliate

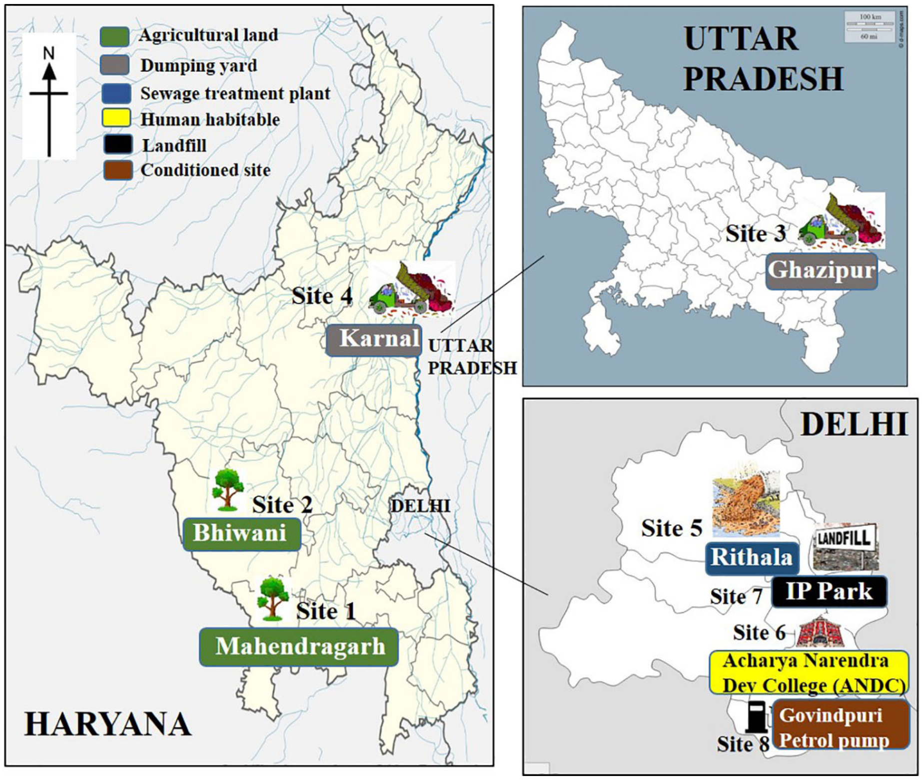

Fig. 1. Maps showing the Delhi region and the position of the eight sampling sites (site 1–8).

Table 1
Locations, descriptive features and anthropogenic activities of the eight sampling sites.

Site	Coordinates (Latitude Longitude)	General features of anthropogenic activity	Annual temperature
1	28°6.0′45″N, 76°13′28.92″E	Agriculture lands, silty soil	24
2	28°40′26.4″N, 75°50′27.6″E	Agriculture lands, sandy soil	28
3	25°21′0.00″N, 90°24′45.0″E	Dump yards, sandy soil	22
4	29°41′8.52″N, 77°59′25.8″E	Dump yards, sandy soil	21
5	28°35′20.4″N, 77°15′54.0″E	Sewage treatment plant, sandy soil	24
6	28°32′20.4″N, 77°15′50.4″E	Residential lands, sandy soil	28
7	28°35′52.8″N, 77°15′14.4″E	Landfill, sandy soil	23
8	28°35′52.8″N, 77°15′50.4″E	Barren lands, petrol pump, sandy soil	28

communities. Agglomerative hierarchical cluster analysis was done using the Euclidean distance matrix method to analyse the similarities between different physicochemical parameters and ciliate communities at different sites (Li et al., 2010a). The bivariate correlation and multiple stepwise regression analyses were used to reveal the relationships between ciliate species abundance/diversity and the physical/chemical soil parameters. Statistical analyses were performed using IBM SPSS 22.0 statistics software.

3. Results

3.1. Physicochemical parameters

Most of the physicochemical factors differed among the eight different sites (Table 2). Conductivity at each site varied, with the lowest value of 1.17 dS/m being at site 6, and the highest value of 1.74 dS/m at sites 1 and 8. The examination of soil samples showed that the values for pH ranged from 6.75 to 8.4, reflecting the neutral and/or slightly alkaline nature of the soil in the Delhi region. The water holding capacity (interstitial water) of soil samples ranged from 12.07% to 24.07%, with minimum and maximum values at sites 8 and 6, respectively. Also, site 6 has the highest values of total organic carbon (2.25%), and total organic matter with values of 3.87%. Total nitrogen content was highest in the sludge sample (site 5) collected from sewage treatment plant, while Bhiwani agricultural land (site 2) recorded the lowest value. The soil texture at sites 2, 3, 4, 5, 6, 7, and 8 was sandy while site 1 had a silty texture. The hierarchical cluster dendrogram revealed that three groups of sites, where the sites in each group exhibit similar soil physicochemical properties and with being similarity between sites: 5 and 6; 1, 2, 7 and 3, 4, 8; respectively (Fig. 4). Water holding capacity, total nitrogen and phosphorus contents have the strongest correlation with ciliate diversity (Table 6).

3.2. Community structure of soil ciliates

In total, 17 species of ciliates, belonging to four classes, seven orders, ten families and 17 genera, were recorded in the soil samples collected during the present study (Tables 3, 4 & Fig. 2). Among these 17 species, spirotrich species were found at more than half of the sampling sites, while the most prevalent species, occurring at all eight sites, were *Oxytricha, Uroleptus* and *Colpoda*. The most dominant group was the Spirotrichea followed by the Colpodea. The total ciliate species number (TSN) at each site varied with soil habitats: the ANDC site (site 6) had the highest TSN with thirteen species, and Gazipur (site 3) had the lowest TSN with just one inhabitant species (Fig. 3 & Table 3). The greatest ciliate diversity was found in Rithala sewage sludge (site 5) and ANDC (site 6) samples whereas, ciliate diversity was lowest in Mahendergarh

Table 2
Main physicochemical properties of the soil in each of the eight sites investigated in and around Delhi region.

	Site							
Soil parameter	1	2	3	4	5	6	7	8
pH	8.4	7.71	8.0	7.64	6.75	6.89	8.1	8.3
Interstitial water (%)	20.5	18.69	18.45	17.35	15.36	24.07	18.94	12.07
Conductivity (dS/m)	1.74	1.64	1.41	1.49	1.41	1.17	1.49	1.74
Total organic matter (%)	1.69	0.48	2.12	2.61	3.87	0.36	1.34	1.62
Total organic carbon (%)	0.98	0.28	1.23	1.51	2.25	0.21	0.78	0.93
Total nitrogen (Kg/ ha)	28.22	21.9	65.85	67.42	250.88	153.66	21.95	34.49
Total phosphorus (ppm)	0.3	0.49	0.10	1.4	1.19	0.81	0.96	0.14

Table 3
List of ciliate taxa indicated by their presence (●) or absence (○) in the soil samples collected from the eight different sites.

Ciliate Taxa	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Anatoliocirrus sp.	○	○	○	●	○	●	○	○
Oxytricha sp.	○	○	●	●	●	●	●	○
Sterkiella sp.	○	○	○	○	●	●	○	○
Paraurostyla sp.	○	○	○	●	○	○	○	○
Stylonychia sp.	○	○	○	○	○	●	○	○
Nudiamphisiella sp.	○	○	○	○	●	●	○	○
Anteholosticha sp.	○	○	○	○	●	●	○	○
Gonostomum sp.	○	○	○	○	●	●	○	○
Fragmospina sp.	○	○	○	○	○	●	○	○
Hemiamphisiella sp.	○	○	○	○	○	●	○	○
Uroleptus sp.	●	●	○	●	○	●	○	○
Euplotes sp.	○	○	○	○	○	○	●	○
Spathidium sp.	○	○	○	○	○	○	○	●
Colpoda sp.	●	●	●	●	●	●	●	●
Dileptus sp.	○	○	○	○	●	●	○	○
Lacrymaria sp.	○	○	○	○	●	●	○	○
Vorticella sp.	○	○	○	●	○	○	○	○
Total taxa present	2	2	2	6	8	13	3	2

Table 4
List of soil ciliate taxa recorded in and around Delhi region during the present study with the constancy of inhabitant species (based on the classification system of Adl et al., 2018).

Class	Order	Family	Species	Constancy of species (%)
Spirotrichea	Stichotrichida	Oxytrichidae	*Anatoliocirrus* sp.	25
			Oxytricha sp.	62.5
			Sterkiella sp.	25
			Paraurostyla sp.	12.5
			Stylonychia sp.	12.5
			Gonostomum sp.	25
			Fragmospina sp.	12.5
		Amphisiellidae	*Nudiamphisiella* sp.	25
			Hemiamphisiella sp.	12.5
		Holostichidae	*Anteholosticha* sp.	25
		Uroleptidae	*Uroleptus* sp.	50
	Euplotida	Euplotidae	*Euplotes* sp.	12.5
Litostomatea	Spathidiida	Spathidiidae	*Spathidium* sp.	12.5
	Dileptida	Dileptidae	*Dileptus* sp.	25
	Haptorida	Lacrymaridae	*Lacrymaria* sp.	25
Oligohymenophorea	Sessilida	Vorticellidae	*Vorticella* sp.	12.5
Colpodea	Colpodida	Colpodidae	*Colpoda* sp.	100
4 classes	7 orders	10 families	17 species	

(site 1) and Bhiwani (site 2) (Table 3). The S/C ratio (spirotrichs/colpodids ratio) was high in ANDC, Rithala and Karnal sites (site 6 > site 5 > site 4) and low in Gazipur and Govindpuri petrol pump site samples (sites 3 and 8) (Fig. 3). The dendrogram shown at the Fig. 5 demonstrated that the soil ciliate communities at sites 3, 4, 5 and 6 had closer relationships. Moreover, ciliate communities at sites 1, 2, 7 and 8 had a closer relationship The hierarchical cluster dendrogram of ciliate abundance and diversity with respect to physicochemical parameters demonstrated that sites 1, 2, 3, 4, 7 and 8 had a closer relationship whereas site 5 and 6 have a closer relationship (Fig. 6). Generally, in the soil samples, the diversity indices were highest at sites 4, 5, 6 and 7, following the order: site 6 > site 5 > site 4 > site 7, whereas the diversity indices were lower at sites 1, 2, 3 and 8, with the order: site 1 > site 8 > site 3 > site 2 (Table 5).

4. Discussion

Although several studies have been conducted on physicochemical analysis of fresh water and soil samples from various parts of India and worldwide (Das and Bindi, 2014; Asema et al., 2015; Vyas et al., 2015) including correlations with microbial diversity;

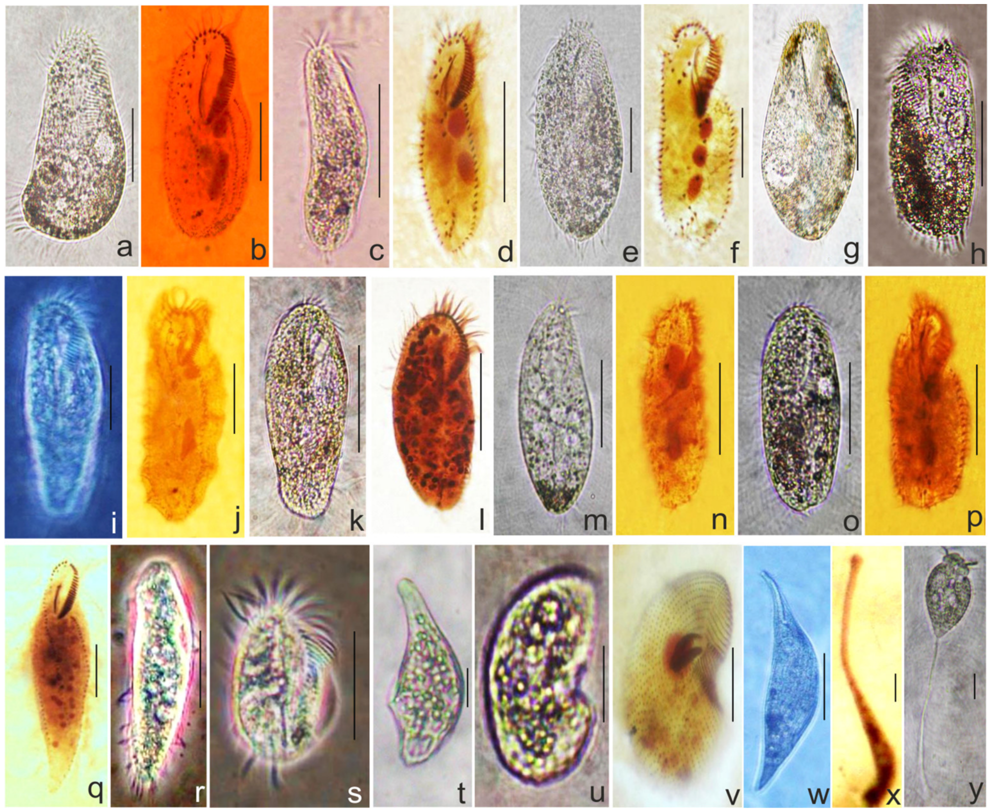

Fig. 2. (a–y) Photomicrographs of soil ciliates from life and after protargol impregnations. (a, b) *Anatoliocirrus* sp. (c, d) *Oxytricha* sp. (e, f) *Sterkiella* sp. (g) *Paraurostyla* sp. (h) *Stylonychia* sp. (i, j) *Nudiamphisella* sp. (k, l) *Anteholosticha* sp. (m, n) *Gonostomum* sp. (o, p) *Fragmospina* sp. (q) *Hemiamphisiella* sp. (r) *Uroleptus* sp. (s) *Euplotes* sp. (t) *Spathidium* sp. (u, v) *Colpoda* sp. (w) *Dileptus* sp. (x) *Lacrymaria* sp. (y) *Vorticella* sp. Scale bars represent 50 μm (a–t and w–y) and 20 μm (u, v).

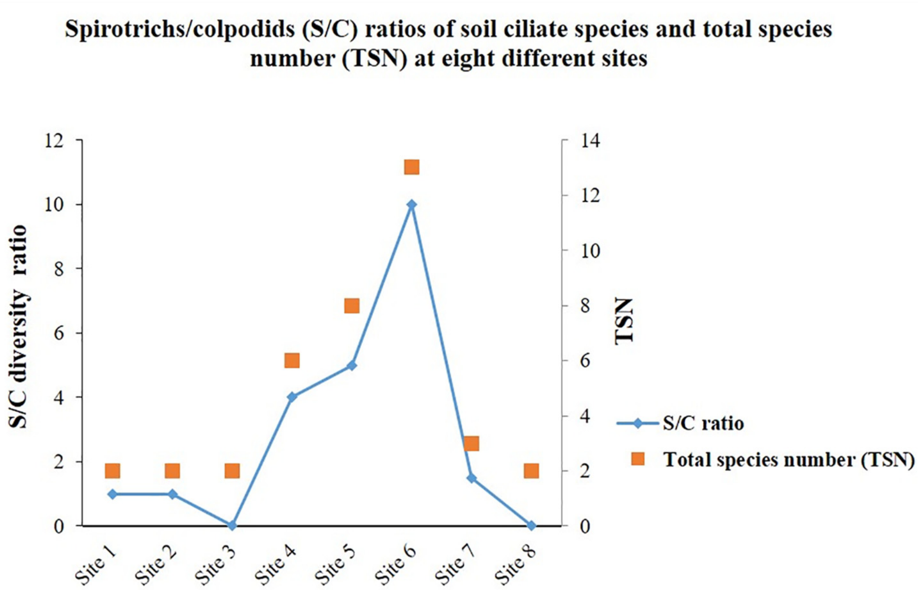

Fig. 3. Spirotrichs/colpodids (S/C) ratio and total soil ciliate species number (TSN) at each sampling site.

very few studies have been reported on the correlation between ciliate community structure and physicochemical properties (Chao et al., 2006; Aguilera et al., 2006; Li et al., 2010a,b; Ting et al., 2012; Fokam et al., 2015; Debastiani et al., 2016) and the information is still more fragmentary from India.

Out of the physicochemical factors, the concentration of the hydrogen ion (pH) is a very important soil property parameter because it determines the availability of nutrients, and characterizes the physical condition controlling the microbial activity in the soil habitat. (Foissner, 1997a). In the present study, the exam-

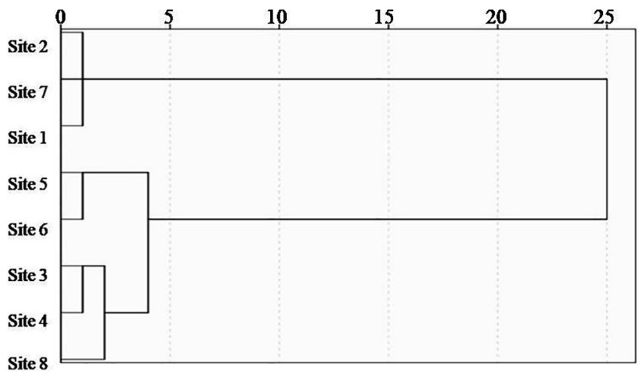

Fig. 4. Dendrogram shows the cluster analysis of soil physicochemical properties at various sampling sites.

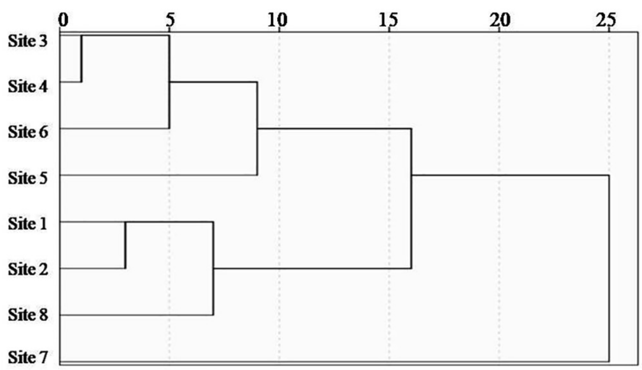

Fig. 5. Dendrogram shows community similarity of soil ciliates at various sampling sites.

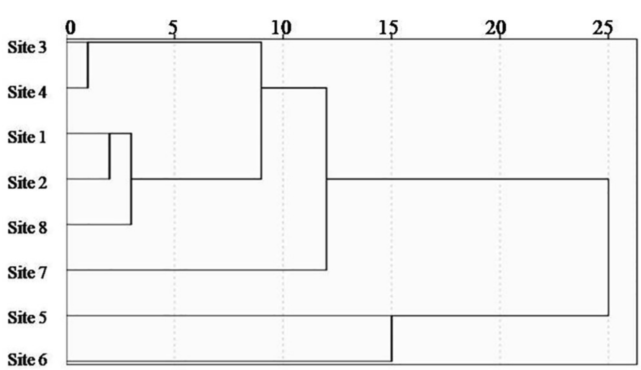

Fig. 6. Dendrogram shows correlation between physicochemical properties and soil ciliate community at various sampling sites.

ined soil samples are either neutral or slightly alkaline (Table 2). There is a good correlation between soil pH and electrical conductivity, with a Pearson correlation coefficient of 0.685. It is known that under alkaline conditions, the solubility of minerals decreases creating nutrient deficiencies in the soil. Ciliate growth is therefore limited even in slightly alkaline soil. The conductivity and the hydrogen ion concentration (pH) frequently affect ciliates distribution and/or activity (Ekelund and Rønn, 1994; Opravilová and Hájek, 2006; Ehrmann et al., 2012) and moreover it affects ciliate species composition, as well as ciliate species diversity and density in the soil (Mitchell et al., 2013; Dupont et al., 2016; Lara et al., 2016).

The interstitial water (water holding capacity) is a measure of soil moisture content. A high soil moisture content indicates that the soil has two main characteristics, firstly, more water washing either from precipitation or from water flooding of neighboring water bodies. Secondly, less water evaporation from these wetlands due to they are being covered by relatively dense vegetation. The water holding capacity shows a positive correlation with the availability of ciliates. For example, site 6, which has the maximum water holding capacity, also has maximum diversity and species abundance (Table 6).

The texture of the soils that recorded from the eight sites during the present study ranged from coarse sand to silty soil (Table 1). Only site 1 had silt soil, with the rest of the sites having sandy soil, with a maximum percentage of gravel in sites 5, 7, 4 and 6 and least in site 1. The ciliate diversity/richness, which quantified as the sand content, increases with the coarseness of soil. This observed trend is an important finding since it indicates that the physical condition of the soil plays a distinguished role that shape and/or characterize the structure of ciliate communities. It has also been observed in the context of bacterial communities, that the coarser soils exert control over community structure by providing more isolated microhabitats, thereby fostering greater richness (Chau et al., 2011). Also, soil ciliates have developed mechanisms to resist desiccation. This mechanism is ample evidence and includes their ability to enter dormant or resting states, such as by encystment (Geisen et al., 2018). Larger pore spaces, therefore, although more prone to desiccation, do not preclude ciliate colonization, and may in fact enhance the survival of ciliate species by providing isolated habitats in which competition for resources is reduced. Thus, in the present investigation, ciliate diversity was more pronounced in sandy soil especially when compared with that of silty soil.

The amount of carbon, nitrogen and phosphorous content in different soil samples is shown in Table 2. The nitrogen content was highest in the sludge sample (site 5) collected from waste water treatment plant and lowest in the Bhiwani agricultural land sample (site 2). Total nitrogen content and phosphorus content have the strongest correlation with ciliate diversity (Table 6). The effect of organic matter, nitrogen and phosphorus on soil ciliates is indirect since it is influenced by the bacterial community inhabiting the soil. There is little information on the relationships between ciliate abundance and soil ammonia-nitrogen or nitrate-nitrogen contents, although total nitrogen has been found to influence soil protozoa abundance (Ning and Shen, 1998). Nitrogen, along with another nutrients, shapes soil protist diversity; that is, ciliates, testate amoebae and algae diversity, and likewise density has been shown to vary strongly along soil nitrogen (N) gradients (Shields

Table 5
Biodiversity indices for the eight sites investigated during the present study.

Biodiversity indices	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Shannon index	0.67	0.27	0.59	1.64	1.99	2.41	1.05	0.61
Dominance index	0.53	0.15	0.42	0.83	0.90	0.93	0.66	0.46
Simpson index	0.92	0.84	0.57	0.16	0.09	0.06	0.33	0.53
Reciprocal Simpson index	2.12	1.18	1.73	5.88	10.91	15.4	3	1.87
Dominance index approximation	0.48	0.14	0.40	0.78	0.90	0.89	0.64	0.42

Table 6
Bivariate correlation of ciliates diversity and abundance with soil physicochemical parameters.

Soil parameter	With respect to ciliate diversity		With respect to ciliate abundance	
	Pearson correlation coefficient	Significance	Pearson correlation coefficient	Significance
Water holding capacity	0.456	0.256	0.533	0.174
pH	−0.862**	0.006	−0.335	0.418
Electrical conductivity	−0.824*	0.012	−0.752*	0.031
Total organic carbon	0.009	0.984	−0.115	0.787
Total organic matter	0.007	0.988	−0.118	0.780
Total nitrogen	0.747*	0.033	0.178	0.673
Total phosphorus	0.564	0.146	0.512	0.194

** Correlation is significant at 0.01 level.
* Correlation is significant at 0.05 level.

and Durrell, 1964; Clarholm, 2002; Acosta-Mercado and Lynn, 2004; Bernasconi et al., 2011). Other work has shown, meanwhile, that, the diversity and density of testate amoebae were reduced by experimental carbon (C) and phosphorus (P) addition but benefited from the addition of nitrogen (N) (Krashevska et al., 2010, 2014). Protozoa play a great and valuable role in mineralizing the soil nutrients, and making them available for use by soil flora and fauna. Ciliate abundance and diversity were found to have positive correlation with nitrogen content. It was previously reported that higher nitrogen content favours the growth of bacteria (e.g. Nitrogen fixing symbiotic bacteria), thereby favouring the growth of ciliates which feed on those bacteria. These soil protists release excess nitrogen consumed from bacteria in the form of ammonium (NH_4^+) (Hoorman, 2011) which is further utilized by plants for their growth and development. Thus, sites 5 (sewage treatment plant) and 6 (ANDC), having higher nitrogen content also had higher ciliate diversity than other sites.

The greatest ciliate diversity was found in the Rithala sewage sludge (site 5) and residential land (site 6) samples as the activated sludge contains active microorganisms which may help in the growth of protists, whereas ciliate diversity was lowest in samples from Mahendergarh (site 1) and Bhiwani (site 2), which could be due to excess use of insecticides and pesticides in these agricultural lands. Diversity indices show that sites 6 > 5 > 4 > 7 had the greatest ciliate species whereas sites 1 > 8 > 3 > 2 had the fewest number of species (Table 3). *Spathidium* sp. was observed in Govindpuri petrol pump sample (site 8). It has been reported that *Spathidium* sp. is normally present in alkaline environments ranging from pH 7.9 to 8.5 (Foissner, 2016). Since areas contaminated with petroleum compounds are hypersaline in nature (Fathepure, 2014), the growth of *Spathidium* sp. was higher in the soil sample collected from site 8. *Colpoda* sp. was present in all the samples examined but were most abundant in the sample from the sewage site. The most dominant group was Spirotrichea followed by Colpodea. Although both, the total species number and abundance differed, the dominant (the Spirotrichea and Colpodea) and rare groups (Oligohymenophorea) from the eight sites were almost the same. This is also in accordance with results from soil samples from other regions of the world (Li et al., 2010b; Foissner, 2016). The most abundant species belong to the class Spirotrichea and Colpodea since they can encyst when the soil moisture decreases, and excyst in a timely manner so as to recover their normal morphological characteristics when the soil moisture increases. Also, with their flattened bodies, the spirotrich ciliates can creep into adjacent soil granules or litter and can escape harsh conditions.

Soil ciliate communities respond to a complex combination of biotic and abiotic factors whose interactions are still far from being understood (Foissner 1997b, 1999; Li et al., 2005; Adl et al., 2006; Zancan et al., 2006; Lara et al., 2007). Moreover, they may also respond to anthropogenic perturbations such as land use intensification, tillage, elevated CO_2, pesticides, fertilizers and pollution (Lentendu et al., 2014; Gabilondo et al., 2015; Imparato et al., 2016; Antonelli et al., 2017).

In this study, ciliate diversity and abundance had a good correlation with the physicochemical properties of the soil (Table 6). From the data presenting in this table (Table 6) it is clear that, water holding capacity (interstitial water), total nitrogen and phosphorous, significantly affected ciliate diversity and abundance. pH and electrical conductivity had a negative correlation with ciliate diversity. Total organic matter and organic carbon have a less strong correlation with ciliate diversity, however, and a negative correlation with ciliate abundance (Table 6). When organic matter is freshly added to the soil, bacterial growth increases tremendously thereby inducing excystment of ciliates, which results in higher ciliate abundance. After some time, however, overcrowding provokes encystment and fewer ciliates (Ekelund et al., 2002). Thus, an increase in organic matter decreases ciliate abundance with time. This shows that the biodiversity of soil ciliates reflects the ecological or environmental quality and suggests that the soil ciliates community with particular reference to their diversity is an important group to evaluate the importance of perturbations in soil systems.

5. Conclusion

Each soil habitat has its own texture, architecture and distinctive pore spaces which affect the microbial community in general and ciliate diversity in particular. Moreover, the species composition and community structure of soil ciliates are closely associated with the type, physical and chemical characteristics of the soil. The study of the biodiversity of soil ciliates from different compositions of soil can help us to estimate the soil quality. In conclusion, ciliate diversity serves as an important, valuable and sensitive bioindicator for assessing soil quality. The assessment of soil quality by ciliates will provide farmers, consumers and policy analysts with critical new information to make informed decisions that will empower society to promote and reward progress towards more sustainable and healthy food production systems.

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