

Original Research Article

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## A Comparative Study on Forest Soil Microbial Diversity and Biomass in Nilgiri Biosphere of Southern India

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### ABSTRACT

It is well-known that Nilgiri forest biosphere in India contains high microbial biodiversity of bacteria, fungi, actinomycetes and nematodes that play an important role in the ecosystem. The present investigation was carried out in the Nilgiri forest ecosystem in the division of North nilgiris, Tamil Nadu, India during 2017-2020 to evaluate the microbial diversity of undisturbed forest soil in two different altitudes viz., Kallar and Ooty with comparison of agro-ecosystem and polluted ecosystem and in four different seasons viz., summer (S1), pre-rainy (S2), post rainy (S3) and winter (S4). Representative soil samples were collected at four different depths (0-15, 15-30, 30-45 and 45-60 cm) during four different seasons (summer, pre-rainy, post-rainy and winter) from all the ecosystem areas of Nilgiri forest ecosystem and were analysed for their availability for population dynamics. Samples taken during post rainy season recorded highest fungal population of  $178 \times 10^5$  CFU/g/soil in the kallar forest ecosystem as compared to the polluted ecosystem and lowest population for bacteria and actinomycetes. The major bacterial genera found in diversity study are occupied by *Bacillus* and *Pseudomonas*, which can survive in high temperature ( $75 \times 10^5$  CFU/g/soil) in summer season. Most of the population ( $>75 \times 10^5$  CFU/g/soil) of fungal genera were found in low temperature and high relative humidity in Post rainy and winter season (*Acrostalagmus*, *Polyporus*, *Phellinus*, *Trichoderma*, *Aspergillus spp.*, *Alternaria*). In one gram of soil, population of bacterial feeding nematodes (*Rhabditis* sp. and *Acrobeles* sp.) dominated in lower altitudes of Kallar which resulted in higher rate of decomposition. Fungal feeding nematodes (*Aphelenchus* sp and *Aphelenchoides* sp.) were more in higher altitudes with soil having acidic pH due to leaching effect favored the growth of fungus. The conclusion drawn from the present study showed an increase in fungal population and fungal feeding nematode population at higher altitudes and reduction in bacterial and actinomycetes population in all the four ecosystems and all the microbial population were highest in post rainy seasons when compared to pre-rainy, summer and winter seasons.

#### Keywords

Forest ecosystem,  
Microbial diversity,  
Bacteria, Fungi,  
Actinomycetes,  
Fungal feeding  
nematodes,  
Bacterial feeding  
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#### Article Info

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## Introduction

Life on the earth is contained with the biosphere which is recognized as a vast and highly complex system made up of millions of genus and species that occupy virtually all the earth's terrestrial and aquatic surfaces. Soil is one of the most diverse habitat on earth and contains one of the most diverse groups of living organisms. The soil microorganisms play an important role in energy flow, nutrient cycling and organic matter turnover in terrestrial ecosystems (Bauhus and Khanna, 1999). The perceived values of soil communities as ecological indicators will be increased by establishing their functional links to ecosystem processes (Debruyne, 1997), determining a hierarchy of geographic scale (Neher *et al.*, 1998) and measuring their utility across boundaries. Biodiversity in soil system is high relative to above and below ground systems (Giller, 1996) form a particular diverse component of the soil biography (Lawton *et al.*, 1996).

The vegetation of the nilgiri forest ecosystem is characteristic of sandy coastal areas, with the prevailing species being *Dalbergia Tectona grandis*, *Spathodeacam panulata*, *Jacaranda mimosifolia*, *Grevillea robusta*, *Pongamia pinnata* and *Kijelia pinnata*. Although, now discontinuous due to deforestation, it is globally one of the most biodiverse ecosystems, containing more than 60% of the flora of the world (Faoro *et al.*, 2010). Being self-sustaining systems, micro-organisms play an important role in the decomposition of organic matter, mineralization of organic compounds and making nutrients available to plants (McGuire *et al.*, 2012). However, populations of micro-organisms and their activities can be influenced by changes in the physio and chemical characteristics of the soil (Costa *et al.*, 2012). According to Fan *et al.*, (2006), the total number of bacteria is positively

correlated with the organic matter content of the soil. As the micro-organisms are directly involved in the cycling of nutrients in the soil, it is important to quantify them to indicate how these processes are occurring in ecosystems and are affecting soil quality (Hafich *et al.*, 2012). The influence of the ecosystem on the number of bacteria (Silva *et al.*, 2008), fungi (Costa *et al.*, 2012) and actinomycetes (Ravikumar *et al.*, 2011) has shown great variability. Nematodes (free-living and plant-parasitic) may be the most useful group for community indicator analysis because more information exists on their taxonomy and feeding roles (Yeates, 1987) than does for other mesofauna. Soil nematodes can be placed into at least five functional or trophic groups (Yeates *et al.*, 1993), and they occupy a central position in the detritus food web. Due to the scarcity of information about the functional role and participation of micro-organisms in coastal ecosystems, the objective of the present study was to analyse seasonal variation in microbial populations and the activities. Forest fire is also degraded the Nilgiri Biosphere Reserve every year.

However, the impact of decreasing the population of flora and fauna, which has been altering the soil microbial properties and it, has not been carried out so far (Saravanan *et al.*, 2013). Keeping the above points in view the present study has been done with an aim to compare the population dynamics of fungi bacteria, actinomycetes and nematodes in comparison of four different ecosystem during summer, pre-rainy, post-rainy and winter seasons. The soil inhabiting microbes from two different altitude zones of Nilgiri forest with a comparative study of the microbial fauna at two different altitude zone (agro ecosystem in eastern block of Tamil Nadu Agricultural university and polluted soil of Ukkadam (town area in Coimbatore district) to assess the role of microbes as

indicators of soil conditions and effects of altitude on microbial communities.

## Materials and Methods

### Survey in selected forests of Nilgiris

The details of the field and laboratory studies conducted and the methods followed are presented here. The present study were carried out in different locations viz., Agro-Ecosystem (Eastern block, 11°00'28.9"N, 76°56'02.4"E), forest ecosystem (Kallar, 11°19'54.1"N, 76°54'01.9"E), forest ecosystem (Ooty, 11°41'43.7"N, 76°69'75.4"E) and polluted ecosystem (Ukkadam, 10°59'12.3"N, 76°58'07.4"E) section of the Nilgiris Range. Soil is generally acidic in reaction and the pH ranges from 5.0 to 6.5. The soil is classified into loamy brown which is rich in organic matter. A preliminary survey was conducted in selected forests of Nilgiris viz., Kunjapanai, Kotagiri and, Ooty in the second fortnight of November, 2017 to determine the occurrence of microbial community and nematodes in forest soils.

A second phase of survey was done during November 2018 in Kallar, Burliyar, Katteri, Conoor and Aravangadu. During the survey, soil and root samples were collected randomly in the forests and from tree species such as *Tectona grandis*, *Spathodea campanulata*, *Jacaranda mimosifolia*, *Grevillea robusta*, *Pongamia pinnata* and *Kijelia pinnata* with an aim of understanding the distribution and occurrence of the microbial diversity and nematode diversity and their role in soil health in the forest soils.

Since the forest ecosystem is totally undisturbed by human activities, the soil samples were filled with more of organic matter (Somasundaram, 2005). Sampling inside the forests was done with prior permission from the State Forest Department.

## Collection of soil samples

### Estimation of microbial population

Soil samples were collected at 0-15 cm depth from the experimental site and analyzed for microbial population and enumeration was done using the serial dilution techniques of Parkinson *et al.*, 1971). Soil microbial analysis was done for enumeration of bacteria, fungi and actinomycetes population using serial dilution  $10^8$ ,  $10^5$  and  $10^2$ , respectively and in appropriate medium (Nutrient Agar, Rose Bengal Agar and Ken Knights Agar) in sterile plates. The composition of each medium is given below. Enumeration was done after 24 hours for bacteria, 48 hours for fungi and six days for actinomycetes. Composition of nutrient media used for soil microbial analysis: i. Bacteria-Nutrient Agar medium (g lit-1): Peptone 5.0, beef extract 3.0, NaCl 5.0, agar 20 and distilled water 1000 ml, ii. Fungi- Martin's Rose Bengal Agar medium (g lit-1): Glucose 10.0, peptone 5.0, KH<sub>2</sub>PO<sub>4</sub> 1.0, MgSO<sub>4</sub> .7H<sub>2</sub>O 0.5, rose bengal 0.33, agar 15.0 and distilled water 1000 ml. iii. Actinomycetes-Ken knight medium (g lit-1): K<sub>2</sub>HPO<sub>4</sub> 1.0, NaNO<sub>3</sub> 0.1, KCl 0.1, MgSO<sub>4</sub>.7H<sub>2</sub>O 0.1, glucose 10.0 and distilled water 1000 ml. The bacterial and fungal isolates were characterized based on their cultural, biochemical properties and microscopic appearances as described by Cheesbrough (2005).

### Estimation of nematode population

Nematodes are usually unevenly distributed in the field especially in the forest soils. Therefore, sampling was done in a random manner with an aim of collecting free living using hand shovel and auger. Samples of 250 g were collected at a depth 20 to 40 cm as the deep inside the drip line removing the top layer soil filled with dried leaves and other

debris. Samples were collected in polythene bags, sealed, labelled and stored in a cool place in order to avoid desiccation of nematodes until processing. Processing soil samples was done by Cobb's (1998) Sieving and Decanting methods based on the difference in size and specific gravity between nematodes and other soil components using brass sieves of different mesh sizes.. Plastic beakers of capacity of 500 ml were processed through modified Baermann's method. Nematodes were recovered by Modified Baermann's Funnel Method (Schindler, 1961) and observed under stereo zoom microscope for further identification.

### Statistical analysis

The experimental data emanated from the present investigation were subjected to statistical scrutiny in order to determine the treatment effect and other factors (Sukhatme and Amble, 1985)

## Results and Discussion

### Bacteria

The population of microbes was found to be affected in polluted soil which could be observed by increase in the bacterial population in the forest ecosystem especially in Kallar ( $78.5 \times 10^8$  CFU  $g^{-1}$ ) and Ooty ( $74.75 \times 10^8$  CFU  $g^{-1}$ ) soil on compared to the Agroecosystem eastern block ( $51.0 \times 10^8$  CFU  $g^{-1}$ ) and polluted soil ( $37.0 \times 10^8$  CFU  $g^{-1}$ ) in nearby town area. Significantly higher population of bacteria was noticed in soil near forest area (Table 1 & 2, Fig. 1).

Among the seasons, soil sample taken from during pre-rainy ( $S_2$ ) and post-rainy ( $S_3$ ) shows more population in all ecosystem than sample taken during summer ( $S_1$ ) and winter ( $S_4$ ), the population rate was decreased in all

ecosystem. In Kallar and Ooty forest area the sample taken during pre-rainy season, the mean bacterial population rate was  $113.0 \times 10^8$  CFU  $g^{-1}$  and post-rainy season mean bacterial population rate was on par with each other ( $125.5 \times 10^8$  CFU  $g^{-1}$ ). This increase in the population of bacteria after raining may be due to the favourable microclimatic conditions *viz.*, moisture content, temperature, active litter decomposition might have accounted for maximum bacterial action during post-rainy season. In addition to that the available phosphorous in Kallar and Ooty forest area soil is 19.6 and 34.6 (kg/ha) respectively and this was evident from the analytical results of soil samples collected during post-rainy season.

Bacteria represent another important, though less explored, integral part of the microbial community in forest soils. For example, recent findings indicate that bacteria commonly harbor genes encoding plant cell wall-degrading enzymes (Berlemont and Martiny, 2015) and contribute significantly to the decomposition of organic matter (Štursová *et al.*, 2012; Eichorst and Kuske, 2012; Lopez-Mondéjar *et al.*, 2016; Brown and Chang, 2014 and Tian *et al.*, 2014). In addition, bacteria are the major natural agents responsible for N fixation in forest ecosystems (Reed *et al.*, 2011) and for other ecosystem processes, such as mineral weathering leading to the release of inorganic nutrients (Uroz *et al.*, 2011). Similarly, Marcin *et al.*, 2013, reported the diversity of soil bacteria (Chao1) in the studied soils was negatively affected by heavy metal pollution. Similarly to our results, Desai *et al.*, (2009) reported decreased diversity of soil bacterial communities in long-term Cr polluted soils. Moffett *et al.*, (2006) applied amplified ribosomal DNA restriction analysis and found that high Zn contents decreased diversity of bacterial communities in arable soils.

The lower and higher bacterial population during pre-rainy seasons, might be due to differences in soil temperature. Among bacteria, *Bacillus* was dominant in all depths after rainy season in all ecosystem. Due to endospore forming capacity, the genus might have tolerated higher cold and thus proliferated heavily after raining. This might have been the possible reason for its greater number over actinomycetes. The lower and higher bacterial population during summer and pre-rainy seasons, respectively might be due to differences in soil temperature.

### **Fungi**

The population of fungi in the Kallar forest areas was found to be higher than that of the other ecosystem which could be well established from their mean values of  $134 \times 10^5$  CFU g<sup>-1</sup> soil, followed by Ooty forest ecosystem, Agro-ecosystem and polluted soil ( $125$ ,  $116.25$  and  $71.5 \times 10^5$  CFU g<sup>-1</sup>) respectively. In the case of seasonal variation, the post rainy and winter season recorded higher value of  $145 \times 10^5$  CFU g<sup>-1</sup> soil followed by  $112.5 \times 10^5$  CFU g<sup>-1</sup> soil. In summer and pre-rainy,  $79.25 \times 10^5$  CFU g<sup>-1</sup> soil and  $110.25 \times 10^5$  CFU g<sup>-1</sup> soil respectively. In winter and post-rainy seasons were found to be on par and similarly pre-rainy and summer season were found to be on par. The combined effect of season and different ecosystem on the population of fungi was statistically non-significant. The highest mean fungi population of  $134 \times 10^5$  CFU g<sup>-1</sup> soil was observed in the post-rainy season under forest areas and the lowest mean value of  $71.5 \times 10^5$  CFU g<sup>-1</sup> soil was recorded in the under polluted soil near town areas. The fungal population was reduced in the polluted area compared to the forest ecosystem areas in comparison to the behavior of bacterial population. Since fungal spores are the main propagules for reproduction of fungi, elimination of spores in polluted summer and

pre rainy would have reduced the total fungal population in soils (Table 1&2, Fig. 2) (Kanagaraj *et al.*, 2017).

Even though soils collected during winter harboured more number of fungi in polluted ecosystem, the difference between post-rainy and winter season was not significant. The fungal population was found to increase from the summer to winter season in ascending order which might be due to the return of favourable climatic conditions in the subsequent seasons. Singh, (1976) reported that the genera, in order of their frequency of isolation the genus viz., *Penicillium*, *Mortierella*, *Oidiodendron*, *Fusarium*, *Aspergillus*, *Mucor*, *Alternaria*, *Chrysosporium*, *Cladosporium*, *Phialophora*, *Trichoderma*, *Rhizopus*, *Absidia*, *Aureobasidium*, *Cephalosporium*, *Colletotrichum*, *Cylindrocarpon*, *Cryptococcus*, *Monilia*, *Myrothecium*, *Phoma*, *Verticillium*, *Cunninghamella*, *Chaetomium* and *Rhizoctonia* were found. Soils from well drained to moist areas yielded a higher number of fungal species than those from dry areas.

### **Actinomycetes**

On comparative analysis, the actinomycetes population in this study area was found to be lower than that of bacteria and fungi. But, the forest areas recorded higher actinomycetes population than that of polluted ecosystem soil which could be noticed from their mean values of  $42.5 \times 10^2$  CFU g<sup>-1</sup> soil and  $17.75 \times 10^2$  CFU g<sup>-1</sup> soil, respectively. The variation in the actinomycetes population among the kallar and Ooty forest area was on par with each other (Table 1 &2, Fig 3).

Similarly, the seasonal influence on the actinomycetes population was observed to be significantly different.

**Table.1** Comparison of microbial population in the different ecosystem of forest soils of the Nilgiri forest with agro-ecosystem and polluted soil influenced by seasons

Area (A)	Bacterial population (X x 10 <sup>8</sup> CFU/g/soil)					Fungal Population (X x 10 <sup>5</sup> CFU/g/soil)					Actinomycetes population (X x 10 <sup>2</sup> CFU/g/soil)				
	S1	S2	S3	S4	Mean (A)	S1	S2	S3	S4	Mean (A)	S1	S2	S3	S4	Mean (A)
<b>Agro-Ecosystem (Eastern block, 11°00'28.9"N, 76°56'02.4"E)</b>	19	94	71	20	51.0	91	113	151	110	116.25	22	15	29	24	22.5
<b>Forest ecosystem (Kallar, 11°19'54.1"N, 76°54'01.9"E)</b>	22	115	131	46	78.5	104	131	178	123	134.0	31	23	62	54	42.5
<b>Forest ecosystem (Ooty, 11°41'43.7"N, 76°69'75.4"E)</b>	25	111	120	43	74.75	96	127	160	117	125.0	32	22	51	43	37.0
<b>Polluted ecosystem (Ukkadam, 10°59'12.3"N, 76°58'07.4"E)</b>	11	63	51	23	37.0	26	70	91	99	71.5	15	12	23	21	17.75
<b>Mean</b>	19.25	95.75	93.25	33	60.31	79.25	110.25	145	112.25	111.69	25	18	41.25	35.5	29.94
			A	S				A	S				A	S	
<b>SEd</b>			2.88	2.75				5.11	3.40				1.05	1.87	
<b>CD (0.05)</b>			6.6	6.3				11.7	7.84				2.43	4.32	

**Table.2** Microbial genera found predominantly in Nilgiri forest ecosystem in different season

S.No.	Details of microbial genera in collected soil sample	Sample analyzed in different season			
		S1	S2	S3	S4
	<b>Bacteria Genera</b>				
1.	<i>Bacillus</i>	+++	+++	+	++
2.	<i>Pseudomonas</i>	+++	++	+	++
3.	<i>Alcaligenes</i>	++	+	+	+++
4.	<i>E. coli</i>	++	++	++	+++
5.	<i>Azospirillum</i>	++	++	+++	+++
6.	<i>Acinetobacter</i>	+	++	+++	+++
7.	<i>Azotobacter</i>	+	+	+++	++
8.	<i>Beijerinckia</i>	++	+	+++	++
9.	<i>Derxia</i>	+	+	++	+
10.	<i>Flavobacterium</i>	+	++	++	+++
11.	<i>Methylobacterium</i>	++	+++	++	++
12.	<i>Xanthobacter</i>	+	++	+++	++
13.	<i>Alcaligenes</i>	+	+	++	+
14.	<i>Paracoccus</i>	+	+	+	+++
	<b>Fungal genera</b>				
1.	<i>Aspergillus flavus</i>	++	+	+++	+++
2.	<i>Aspergillus niger</i>	+	+	+++	+++
3.	<i>Fusarium</i>	+++	+++	++	+
4.	<i>Curvularia</i>	++	++	+++	++
5.	<i>Penicillium</i>	++	++	++	+++
6.	<i>Alternaria</i>	++	+	+++	+++
7.	<i>Rhizopus</i>	++	+	++	++
8.	<i>Trichoderma</i>	+	+	+++	+++
9.	<i>Phellinus</i>	++	++	+++	+++
10.	<i>Polyporus</i>	+	+	+++	+++
11.	<i>Daedalea</i>	+	++	++	++
12.	<i>Cladosporium</i>	+	++	++	++
13.	<i>Mortierella</i>	++	+	++	+++
14.	<i>Rhizoctonia</i>	++	+	++	+++
15.	<i>Acrostalagmus</i>	+	++	+++	+++
	<b>Actinomycetes</b>				
1.	<i>Streptomyces</i>	+	++	+++	+++

+ : Population < 25 x10<sup>5</sup> CFU/g/soil++ : Population < 50 x10<sup>5</sup> CFU/g/soil+++ : Population < 75 x10<sup>5</sup> CFU/g/soil

**Table.3** Different trophic groups of nematodes observed in the forest soil ecosystem

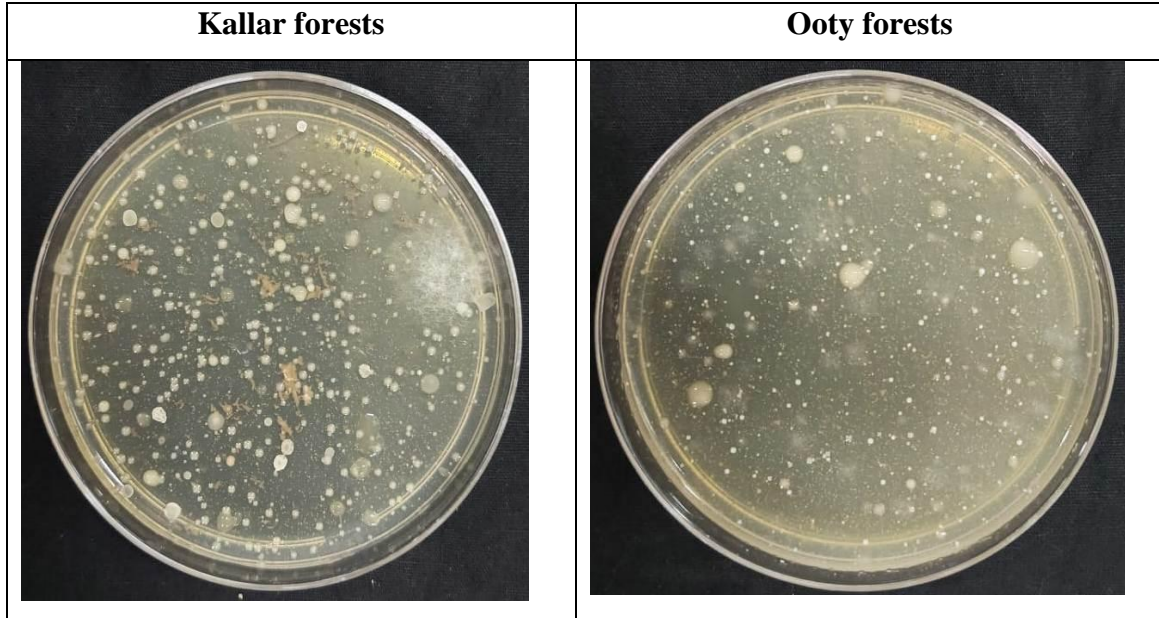
S.No.	Trophic Level of Nematode	Genus of Nematodes Identified
1.	Bacterial feeding nematodes	<i>Rhabditis sp.</i> <i>Acrobelus sp.</i> <i>Acrobeloides sp.</i> <i>Caenorhabditis sp.</i>
2.	Herbivorous nematodes or Plant parasitic nematodes	<i>Helicotylenchus sp.</i> <i>Psilenchus sp.</i> <i>Longidorus sp.</i>
3.	Fungal feeding nematodes	<i>Aphelenchus sp.</i> <i>Aphelenchoides sp.</i>

**Table.4** Comparison of Nematode population in the different ecosystem of forest soils of the Nilgiri forest with agro-ecosystem and polluted soil as influenced by seasons

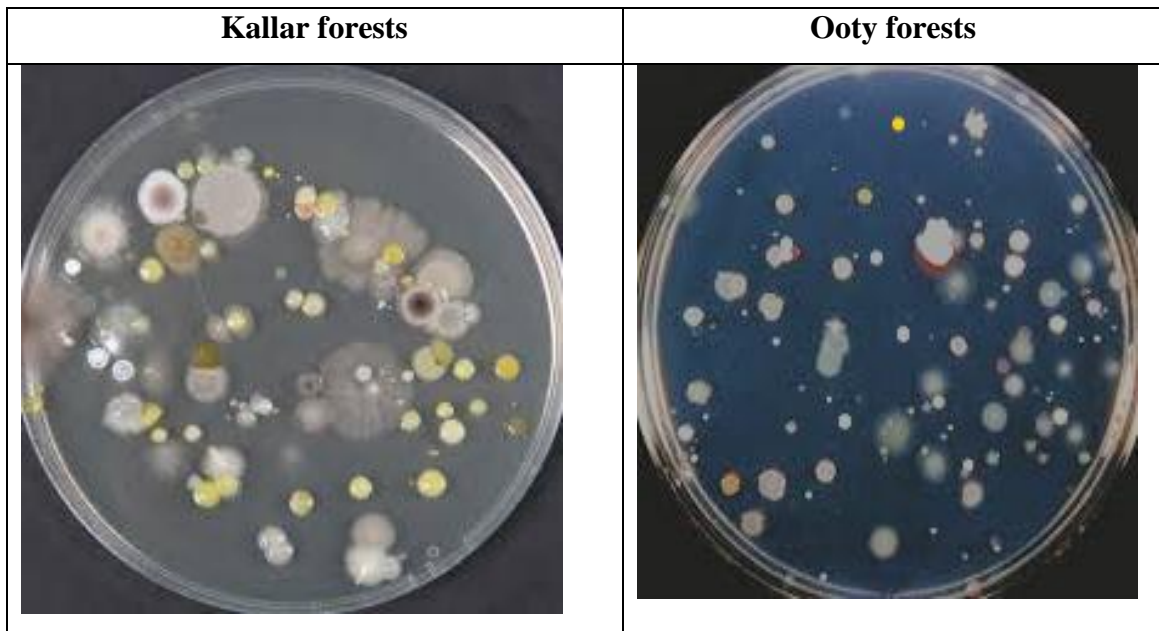
Area	Fungal feeding nematodes (Nos. in 250 g soil)					Bacterial feeding nematodes (Nos. in 250 g soil)				
	S1	S2	S3	S4	Mean	S1	S2	S3	S4	Mean
Agro-Ecosystem (Eastern block, 11°00'28.9"N, 76°56'02.4"E)	39	11	23	29	25.5	56	41	79	13	47.25
Forest ecosystem (Kallar, 11°19'54.1"N, 76°54'01.9"E)	76	30	19	66	47.75	145	86	130	125	121.5
Forest ecosystem (Ooty, 11°41'43.7"N, 76°69'75.4"E)	196	130	91	102	129.75	86	72	48	97	75.75
Polluted ecosystem (Ukkadam, 10°59'12.3"N, 76°58'07.4"E)	-	-	-	-	-	23	-	13	19	18.33
<b>Mean</b>					67.66					65.71
<b>SEd</b>					0.85					0.30
<b>SD (0.05)</b>					2.08					0.69



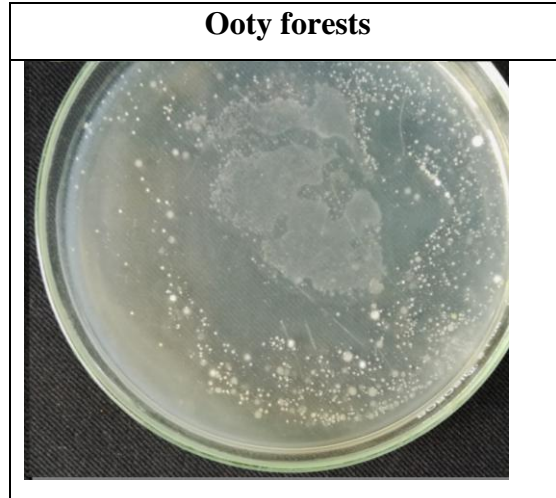
**Plate.1** Serial dilution to assess bacterial population



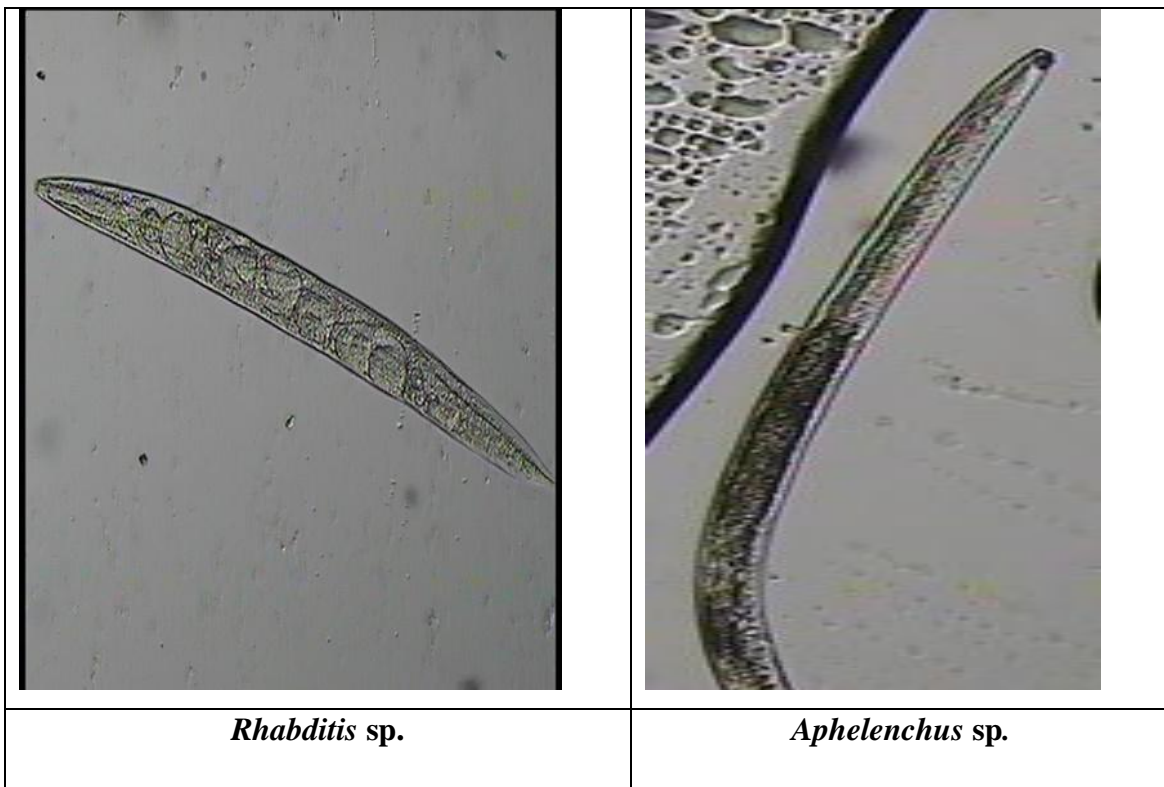
**Plate.2** Serial dilution to assess bacterial population



**Plate.3** Serial dilution to assess Actinomycetes population



**Plate.4** Bacterial and fungal feeding nematodes



The highest mean value of  $41.25 \times 10^2$  CFU g<sup>-1</sup> soil and of  $35.5 \times 10^2$  CFU g<sup>-1</sup> was recorded in post-rainy and winter seasons and the lowest mean value of  $18 \times 10^2$  CFU g<sup>-1</sup> soil was recorded in the pre-rainy season irrespective of the all ecosystem areas. The post-rainy (S3) and winter (S4) seasons were found to be on par and so was the case with summer (S1) and pre-rainy (S2) seasons. On the contrary, the interaction effect of ecosystem and season on actinomycetes population was observed to be non-significant. The highest mean value of  $62 \times 10^2$  CFU g<sup>-1</sup> soil was noted in post rainy season under Kallar forest ecosystem area and the lowest mean value of  $12 \times 10^2$  CFU g<sup>-1</sup> soil were recorded in pre rainy seasons of polluted ecosystem near town area. In summer season, the actinomycetes population was found to be low due to adverse temperature and poor environmental condition and then the population increased during winter season due to the return of favourable environment. Similarly, Srivastava, (2002) reported that the actinomycetes population was higher during winter season when compared to all other seasons. The population of microbes got reduced heavily in polluted soil ecosystem (Golińska and Dahm, 2011).

As in the case of bacterial population, the actinomycetes population also recorded a significantly lower population in polluted ecosystem areas as compared to the forest areas due to the effect of unhealthy soil and decreased on spore formation. It is perceived that the heavy metals and toxin residue generated in the soil in the polluted ecosystem, this might have inhibited the spore formation and also eliminated beneficial microbes. However, it is anticipated that since sewage sludge, manures, and other organic materials will be applied to soil as fertilizer, the concentration of heavy metals may increase in soil (Lexmond and deHaan 1977;

Kobayashi 1985; Anzai and Matsumoto 1987; Iwasaki *et al.*, 1990).

### **Nematodes**

The population dynamics of fungal and bacterial feeding nematodes was influenced by the seasonal soil temperature and altitude. Fungal feeding nematode population in Ooty was more (129.75) when compared to Kallar (47.75 in 250 g soil) with soil having acidic pH due to leaching effect favored the growth of fungus and actinomycetes. Significantly higher population of bacterial feeding nematodes was recorded in lower altitudes of Nilgiris (121.5) in Kallar which resulted in higher rate of decomposition and in turn increased the organic carbon content where are the population decreased in the higher altitude (75.75). They enhance the decomposition process and nutrient mineralization due to release of excess nitrogen assimilated in the bacteria. Population of nematodes was lowest on the polluted soils which indicate the presence of toxic chemicals in the soil that reduced the population of beneficial nematodes (Table 3 & 4, Fig 4).

A total of fourteen bacterial strains, fifteen fungal species and one actinomycetes were predominantly identified and isolated from Nilgiri forest ecosystem soils in summer, pre-rainy, post rainy and winter. Bacterial population found to be high in post rainy, winter and summer season. The population of *Bacillus* sp. and *Pseudomonas* sp. was more than  $30 \times 10^5$  CFU/g/soil in summer season also (Table 3). Bacterial population was dominated by *Bacillus*, *Pseudomonas*, *Alcaligenes* and *E. coli*. Most of the bacteria species can tolerate high temperature and survive in summer season. *Aspergillus flavus*, *Aspergillus niger*, *Fusarium*, *Curvularia*, *Penicillium*, *Alternaria*, *Rhizopus* and *Trichoderma* were the dominant fungal

community found among the soil samples from these study sites. The number of microorganisms in the soil and their diversity depend on many factors, both biotic and abiotic ones (Schlegel 2000; Saadoun and Gharaibeh, 2003). Similarly, Munna *et al.*, 2015 reported that the critical temperature (the temperature above which it is no longer possible to survive) of *Bacillus* spp. SUBB01 was estimated to be 53 °C. The endospores are tough dormant structures that form inside the cell wall of certain types of bacteria, such as *Bacillus* bacteria. These tough capsules form in response to adverse conditions such as drought or high temperatures. They are also resistant to ultraviolet radiation, desiccation, extreme freezing, and chemical disinfectants.

The fungi genera (*Acrostalagmus*, *Polyporus*, *Phelliinus*, *Trichoderma*, *Aspergillus* spp., *Alternaria*) can survive in all seasons in a population of  $< 50 \times 10^5$  CFU/g/soil (Table 3). But in pre rainy season the species, *Fusarium* can available in a range of  $20 \times 10^5$  CFU/g/soil. Most of the fungal pathogens were available in winter and post rainy season ( $< 75 \times 10^5$  CFU/g/soil). Hence, the fungal spores cannot with stand high temperature compare to bacteria and actinomycetes. Cao *et al.*, 2007 reported that the optimum temperature for growth of *Penicillium marneffeii* is lies between 17-28<sup>0</sup> C. Abrashev *et al.*, 2015 reported that, temperatures above 30 °C lead to growth suppression and changes in morphological characteristics: decrease in the size of hyphal elements and increase in "active length" by switching from slightly branched long filaments to a multitude of branched forms.

Likewise fungi, actinomycetes can also survive in low temperature and high relative humidity. The only genus available in actinomycetes is *Streptomyces*. Akond *et al.*, 2016 reported that normal growth and maintenance the temperature at a range of 25-

30°C are usually used for incubation of the great majority of *Streptomyces*, *Nocardia*, and *Micromonospora*. In most soils there are  $10^4$  to  $10^7$  colony forming units (CFU) of actinomycetes in 1 gram soil which constitutes 1–20% of the total number of microorganisms (Dahm *et al.*, 1986; Shirokikh *et al.*, 2002). Among them representatives of the Streptomycetaceae family, mainly the genus *Streptomyces*, make up 90% or even more of all actinomycetes.

Nematode population is directly linked with the soil health by being as good indicators. They play a major role in nutrient mineralization and mobilization. The bacterial feeders (*Rhabditis* sp, *Acrobelus* sp, saprophytes) and fungal feeders (*Aphelenchus* sp., *Filenchus* sp.) are found to be predominantly present in undisturbed forest soils collected. Acidic soil pH in Ooty was due to leaching effect which favoured the growth of fungus and actinomycetes that are food source of fungal feeding nematodes *viz.*, *Aphelenchus* sp. Hence highest population of fungal feeding nematodes was recorded in Ooty forest soils. Similarly high bacterial population and bacterial feeding nematode population resulted in the increased rate of decomposition which in turn increased Organic Carbon content. The organic carbon content was high in Ooty which increased as the altitude increased *i.e.*, from Kallar to Ooty. It is inferred from the study that the abundance of high bacterial and feeding nematodes in forest soils of hilly region contributed contribute for the nutrient mineralization and decomposition of organic matter than in the agricultural soils which are exposed high degree of human intervention. The occurrence of these beneficial nematodes is almost negligible due to the contamination of soil by industrial and city wastes.

In conclusion, it is inferred from the study that the abundance of high bacteria and fungi in forest soils of hilly region contributed for

the nutrient mineralization and decomposition of organic matter than in the agricultural soils which are exposed high degree of human intervention. The occurrence of these beneficial fungi, bacteria, actinomycetes and nematodes is almost negligible due to the contamination of soil by industrial and city wastes. However, this study suggests that heavy metal in polluted soil also affects sensitive microorganisms such as fungi, bacteria, actinomycetes and nematodes at even lower concentrations. Microorganisms contribute to plant growth through various functions in soil. It is also understood that the quality of plant residues accumulating in these different forest sites are furthermore important and may play a vital role in soil microbial population. This microbial populations study at different forest types in the nilgiri forest ecosystem not providing information on microbial diversity, but also will provide information to explore the important microorganisms for various biotechnological application. Hence, by decreasing the dumping of agricultural chemicals and other industrial wastes in the soil the beneficial microbes can be conserved which play an indispensable role in the soil health and furthermore research should be carried out on the effects of heavy metals on soil microorganisms.

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