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Microbial activities and nutrients dynamics in sacred forest of Meghalaya

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Abstract

Fungi and bacteria populations, urease and phosphatase activities and various physico chemical characteristics of the disturbed and undisturbed forest soils were investigated for a period of one year. We found that fungal and bacterial populations exhibited almost a similar trend of monthly variations in the soils of the disturbed and undisturbed forest stands during the study period. The soil of the undisturbed forest stand harbored higher fungal and bacterial populations as compared to that of the disturbed forest stand. It was observed that the urease and phosphatase activities were slightly higher in the disturbed forest stand than that in the undisturbed forest stand. The urease activity was found to be maximum in the month of June and minimum in the month of January in both the forest stands, whereas, in the case of phosphatase activity the maximum activity was observed in the month of July and minimum in the month of November. Fungal population showed a positive significant correlation with soil temperature ($P \leq 0.01$), moisture content ($P \leq 0.01$), organic carbon ($P \leq 0.05$), available phosphorus ($P \leq 0.05$) and exchangeable potassium ($P \leq 0.01$) and negatively significant with pH ($P \leq 0.05$) in both the forest stands, however, a significant positive correlation was found between the fungal population and total nitrogen ($P \leq 0.05$) in undisturbed forest stand only. The one way analysis of variation of fungal, bacterial populations and phosphatase activity showed significant variation ($P \leq 0.05$) at the three different depths between the two study sites.

Key words: Activities; Bacteria; Disturbed; Enzymes; Forest; Fungi; Phosphatase; Undisturbed; Urease.

Introduction

Soil microbes and plant roots are sources of extracellular enzymes, mainly through either secretion from living cells or from lysed cells (Burns, 1982). Once in the soil, enzyme may be protected from denaturation by being absorbed into organic or inorganic surfaces (Pang and Kolenko, 1986). In this absorbed state, extracellular enzymes developed stability to desiccation and heat and can remain active for several years (Miller and Dick, 1995). Under favourable conditions, microorganisms increase most of the enzyme activity. The effect of plants on soil enzymatic activity is due to changes in organic matter content and microbial populations, but is also formed by accumulated enzymes and by continuous release of extracellular and endocellular enzymes; all of which originate in the plant root. The overall enzyme activity of the soil is derived from the activity of accumulated enzymes and from that of proliferating microorganisms (Burns, 1982; Tabatabai and Fu, 1992). Urease and phosphatase have been the most commonly studied soil enzymes which provide an index of total biological activity. Urease enzyme is responsible for the break-down of urea into carbon dioxide and ammonia. It acts as an intermediary enzyme in the transformation of organic N, while phosphatase estimate the breakdown of organic phosphate compound and release of phosphate in the soil

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(Cosgrove, 1967). The term 'phosphatase' has been widely used to describe a group of enzymes that catalyze and hydrolyse both esters and anhydrides of phosphoric acid (Schmidt and Laskowski, 1961). The phosphatase activity of soil has been shown to vary with the standing vegetation (Neal, 1973). Phosphatase has been found to be a good indicator of the organic matter (Hattori, 1988) and is involved in the release of phosphorus compounds in the soil (Rastin *et al*., 1988). The biological activity in soil provides better insight in the understanding of transformation of organic matter (Pietikainen and Fritze, 1995). The estimation of the urease and phosphatase activities provides an assessment of different microbe-mediated processes in soil and gives the most reliable measures of microbial activity. Therefore, knowledge about enzyme activities and their temporal and seasonal variations in soil has considerable biological significance.

Soil microorganisms are of great importance for soil ecosystems because they affect plant available nutrients and soil structural stability (Paul and Clark, 1989). The abundance, size and activity of the microbial populations depend on the quantity and quality of organic matter, texture, and other environmental factors e.g. soil type, nutrient status, pH, moisture as well as plant factors e.g. species, age (Insam *et al*., 1989; Kaiser *et al*. 1992). Fungi and bacteria control many of the vital processes on which the very maintenance and survival of tropical forests depend (Hawksworth and Colwell, 1992). Microbial growth in soil is carbon limited and therefore, the presence of organic matter has the greatest influence on microbial populations (Lynch and Whipps, 1990; Wardle, 1992). An overview of the role of microorganisms in ecosystem functioning as a whole has been presented by Allsopp *et al*. (1995).

Materials and methods

Study site

The study was conducted in the year 2002, in the sacred forest of Nongkrem village, 20 km away from Shillong located at an altitude of 1786 msl. In this study we selected two sites, disturbed forest stand and undisturbed forest stand. The undisturbed forest stand is a protected area with dense vegetation. The dominant tree species recorded include *Cinnamomum glanduliferum*, *Elaeocarpus lancifolius*, *Eurya acuminata*, *Lithocarpus dealbatus*, *Myrica esculenta*, *Pinus kesiya* and *Schima khasiana* together with few shrubs and herbs. In some places, ferns grow thickly and cover the ground area. On the other hand, the disturbed forest stand is thinly populated with few pine trees (*Pinus kesiya*) and other tree species such as *Eleagnus pyriformis* and *Myrica esculenta*. The ground area is covered with grasses and herbs along with few shrubs.

Method

Soil samplings were collected from both the forest stands at monthly intervals for a period of one year. The samples were collected randomly at three different depths i.e., 0-10cm, 10-20 cm and 20-30 cm at each study site. Various estimations were carried out within 24 hour of collection. Collections were done in aseptic conditions and the samples were brought to the laboratory and stored at a temperature of 4^{o}C.

Isolation of fungi and bacteria

Serial dilution plate method (Johnson and Curl, 1972) was followed for the isolation of fungi and bacteria using Rose Bengal Agar Medium (Martin, 1950) and Nutrient Agar Medium (Difco manual, 1953) respectively. Three replicates were maintained for each sample. The colony forming unit (CFU) of fungi and bacteria per gram soil was calculated on the dry weight basis.

Enzyme assay

Urease and Phosphatase activities were determined by the methods of McGarity and Myers (1967) and Tabatabai and Bremner (1969) respectively.

Estimation of Physico-Chemical Characteristic

The temperature (ST), pH, moisture content (MC), organic carbon (OC), total nitrogen (TN), available phosphorus (AP), exchangeable

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Table 1. Correlation coefficient (r) values among microbial populations, enzymes activities and physico-chemical characteristics in the disturbed forest soil

Soil properties	URA	PA	ST	MC	pH	OC	TN	AP	K
FP	-0.23***	0	0.24**	0.26**	-0.44***	0.34***	0	0.53***	0.24**
BP	0	-0.29**	0	0	-0.38***	0	0	0.46***	0
URA		0	0	-0.28***	0	0	0	0	0
PA			0.31***	0	0.20*	0.31***	0.25**	0.23*	0.41***
ST				0.41***	0	0.27**	0	0	0.43***
MC					0	0	0	0	0.23*
pH						0	0	-0.47***	0
OC							0.23***	0.19*	0.46***
TN								0.43***	0

***Note**: FP= fungal population, BP= bacterial population, URA=urease activity, PA=Phosphatase activity, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium).Values marked with*, ** and *** are significant at P≤0.05, P≤0.01 and P≤0.001 respectively; insignificant values are marked with '0'*

potassium (K) of the soil were also analyzed. pH of the soil was read in a digital pH meter. Soil moisture content was determined by drying 10.0 g of the sample in a hot air oven at 105^{o}C for 24 h and reweighing the dried samples till a constant weight was obtained. For analysis of organic carbon, total nitrogen, available phosphorus and exchangeable potassium the soil samples were air dried and sieved in a 0.2 mm sieve. Organic C was determined following the method of Anderson and Ingram (1993). Total N, available phosphorus and exchangeable potassium were estimated following micro- kjeldahl's (Anderson and Ingram, 1993), molybdenum blue method (Allen *et al.,* 1974) and flame photometer (Jackson, 1973) respectively.

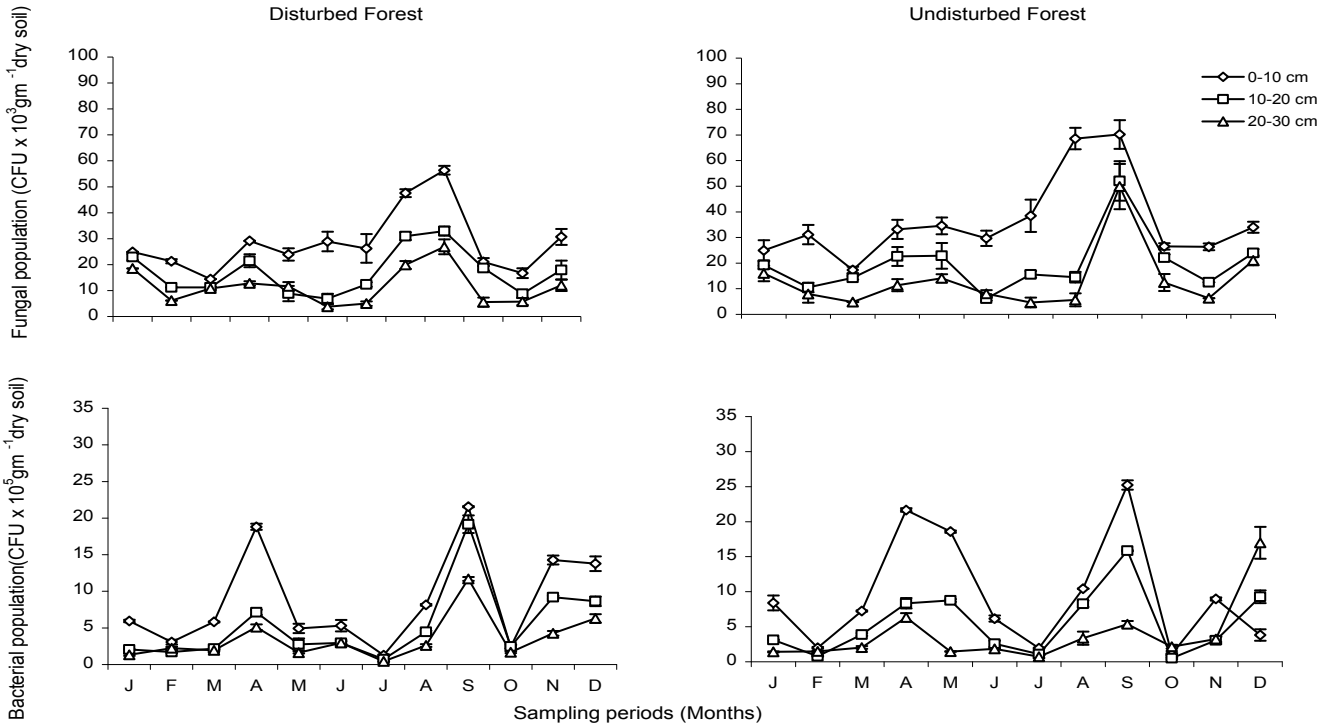

Fig. 1 Fungal and Bacterial populations in the disturbed and undisturbed forest soils at three different depths 0-10cm, 10-20cm and 20-30cm during the study period 2002

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Table 2. Correlation coefficient (r) values among microbial populations, enzymes activities and physico-chemical characteristics in the undisturbed forest soil

Soil properties	URA	PA	ST	MC	pH	OC	TN	AP	K
FP	0	0	0.24**	0.39***	-0.35***	0.37***	0.22*	0.44***	0.36***
BP	0	0	0	0.52***	0	0.33***	0.39***	0.19***	0.28**
URA		0	-0.26**	0	0	-0.26**	0.41***	0	0
PA		0	0.39***	0.29*	0	0.30***	0.26*	0	0.29*
ST			0	0.29***	-0.44***	0	0	0	0.28***
MC				0	0	0.55***	0.62***	-0.21*	0.21*
pH						0	0	-0.38***	0
OC							0.55***	0	0
TN								0	0

***Note**: FP= fungal population, BP= bacterial population, URA= urease activity, PA= Phosphatase activity, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium) Values marked with *, ** and *** are significant at P≤0.05, P≤0.01 and P≤0.001 respectively; insignificant values are marked with '0'*

Results

Fungi and Bacteria Population

Similar trend of monthly variations was observed in the soil of both the forest stands. However, the soil of the undisturbed forest harbored higher fungal and bacterial population as compared to that of disturbed forest. The surface layer had higher fungal and bacterial populations and showed a decreasing trend with increase in depth in both the forest stands. Maximum fungal population was observed in the month of September in both the study sites and the minimum was recorded in the month of March and June in the undisturbed and disturbed forest soils respectively. In general, the population was found

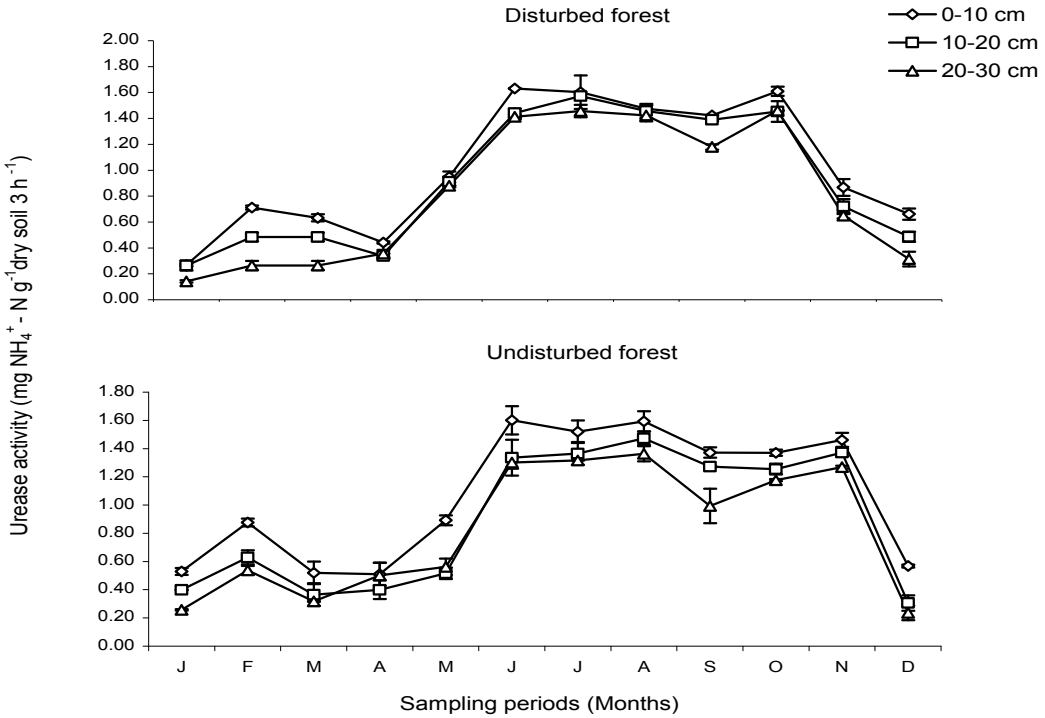

Fig. 2 Urease activity in disturbed and undisturbed forest soils at three different depths 0-10cm, 10-20cm and 20-30cm during the study period 2002

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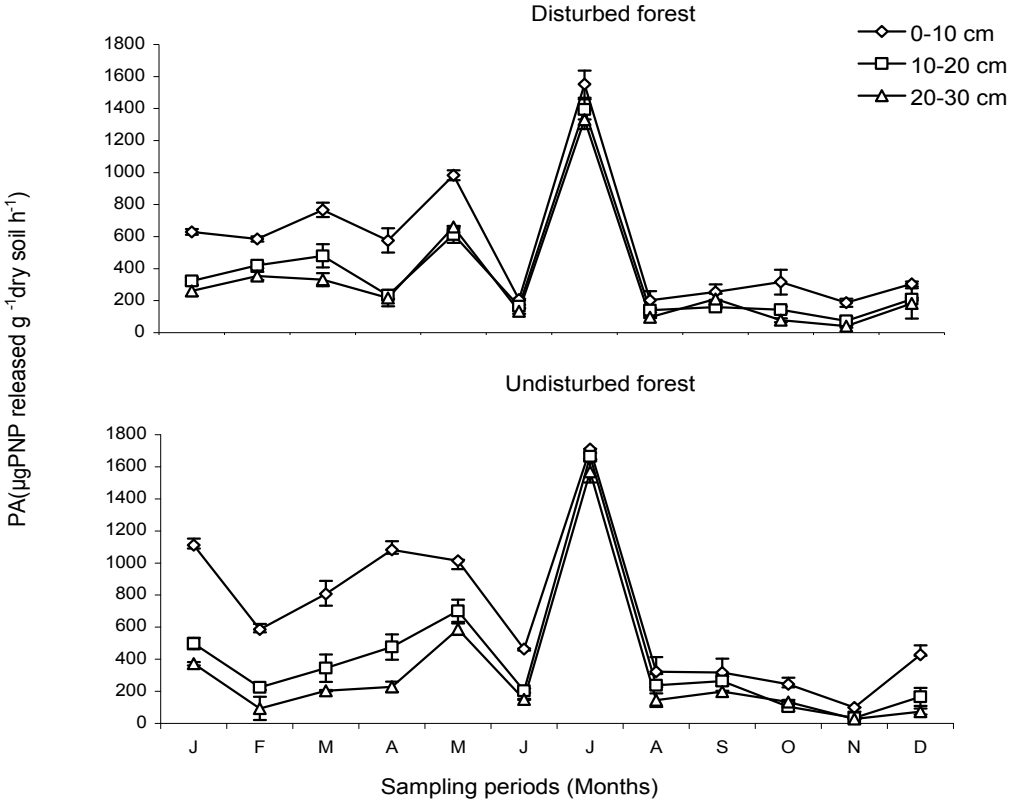

Fig. 3 Phosphatase activity in disturbed sand undisturbed forest soils at three different depths 0-10cm,10-20cm and 20-30cm during

to be higher in summer rainy seasons and lower population was observed in winter months. The maximum bacterial population was recorded in the month of September and minimum was observed in the month of July in both the study sites. The bacterial population decreases with increase in depth (Fig.1).

Fungal population showed a positive significant correlation with soil temperature (ST) ($P \leq 0.01$), moisture content (MC) ($P \leq 0.01$), organic carbon (OC) ($P \leq 0.05$), available phosphorus (AP) ($P \leq 0.05$) and exchangeable potassium (K) ($P \leq 0.01$) and negatively significant with pH ($P \leq 0.05$) in both the forest stands, however, a significant positive correlation was found between the fungal population and total nitrogen (TN) ($P \leq 0.05$) in undisturbed forest soil only. The bacterial population showed a positive correlation with MC ($P \leq 0.05$), OC ($P \leq 0.05$), TN ($P \leq 0.05$), AP ($P \leq 0.05$), K ($P \leq 0.01$) (Table 1 & 2).

Urease

Comparing both the forest stands, it was observed that the urease activity was slightly higher in the soil of disturbed forest than that of undisturbed forest. The activity was maximum in the month of June and minimum in the month of January in both the study sites. The activity decreased with increase in depths (Fig. 2).

Phosphatase

Similar trend of monthly variations was observed in both the forest stands. Slightly higher activity was found in the soil of disturbed forest as compared to undisturbed forest soil. It was observed that the months of July and November showed maximum and minimum activity at three different depths in both the forest soils (Fig.3).

Urease activity showed a positive significant correlation with TN ($P \leq 0.01$). Phosphatase activity showed a positive significant correlation

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Table 3. One-way analysis of variance (ANOVA) of microbial populations (fungi and bacteria) urease and dehydrogenase activities between the disturbed forest (DF) and undisturbed forest (UDF) soils at three different depths 0-10cm, 10-20cm and 20-30cm ($P \leq 0.05$)

Soil properties	Source of variation	F-ratio	P-level
Fungal population	DF(0-10cm) x UDF(0-10cm)	4.79	$3.02x10^{-2}$
	DF(0-10cm) x UDF(10-20cm)	4.59	$3.37x10^{-2}$
	DF(0-10cm) x UDF(20-30cm)	47.61	$1x10^{-3}$
	DF(10-20cm) x UDF(0-10cm)	50.64	$1x10^{-3}$
	DF(10-20cm) x UDF(10-20cm)	5.76	$1.76x10^{-2}$
	DF(10-20cm) x UDF(20-30cm)	4.97	$2.73x10^{-2}$
	DF(20-30cm) x UDF(0-10cm)	94.87	$1X10^{-3}$
	DF(20-30cm) x UDF(10-20cm)	26.71	$1x10^{-6}$
	DF(20-30cm) x UDF(20-30cm)	0	0
Bacterial population	DF(0-10cm) x UDF(0-10cm)	0	0
	DF(0-10cm) x UDF(10-20cm)	5.41	$2.14x10^{-2}$
	DF(0-10cm) x UDF(20-30cm)	10.86	$1.24x10^{-3}$
	DF(10-20cm) x UDF(0-10cm)	13.09	$4.10x10^{-4}$
	DF(10-20cm) x UDF(10-20cm)	0	0
	DF(10-20cm) x UDF(20-30cm)	0	0
	DF(20-30cm) x UDF(0-10cm)	28.19	$1x10^{-3}$
	DF(20-30cm) x UDF(10-20cm)	7.53	$6.84x10^{-3}$
	DF(20-30cm) x UDF(20-30cm)	0	0
Urease activity	DF(0-10cm) x UDF(0-10cm)	0	0
	DF(0-10cm) x UDF(10-20cm)	0	0
	DF(0-10cm) x UDF(20-30cm)	0	0
	DF(10-20cm) x UDF(0-10cm)	0	0
	DF(10-20cm) x UDF(10-20cm)	0	0
	DF(10-20cm) x UDF(20-30cm)	0	0
	DF(20-30cm) x UDF(0-10cm)	0	0
	DF(20-30cm) x UDF(10-20cm)	0	0
	DF(20-30cm) x UDF(20-30cm)	0	0
Phosphatase activity	DF(0-10cm) x UDF(0-10cm)	0	0
	DF(0-10cm) x UDF(10-20cm)	6.44	$1.3x10^{2}$
	DF(0-10cm) x UDF(20-30cm)	0	0
	DF(10-20cm) x UDF(0-10cm)	9.40	$3x10^{3}$
	DF(10-20cm) x UDF(10-20cm)	0	0
	DF(10-20cm) x UDF(20-30cm)	0	0
	DF(20-30cm) x UDF(0-10cm)	7.25	$8.8x10^{3}$
	DF(20-30cm) x UDF(10-20cm)	0	0
	DF(20-30cm) x UDF(20-30cm)	0	0

Note: *Insignificant values are marked with '0'*

with ST ($P \leq 0.01$), OC ($P \leq 0.01$), MC ($P \leq 0.05$), TN ($P \leq 0.05$), AP ($P \leq 0.05$) and K ($P \leq 0.05$) in both the study sites (Table 1 & 2). The one way analysis of variation (ANOVA) of fungal, bacterial populations and phosphatase activity showed significant variation ($P \leq 0.05$) at the three different depths between the two study sites (Table 3 & 4).

Physico-chemical characteristics

Among various physico-chemical characteristics of the soil, the undisturbed forest stand contained higher moisture content, temperature and P than that of the disturbed forest, whereas, organic C and total N were found to be higher in the soil of disturbed forest as compared to that of undisturbed forest soil. Not much variation was observed in pH throughout the months in both the study sites. pH of the soil in both the study sites was acidic being more acidic in undisturbed forest soil. The maximum moisture content was observed during rainy season in both the sites. The soil organic carbon content of both the study sites showed

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Table 4. One way analysis of variance (ANOVA) of microbial populations (fungi and bacteria) urease and dehydrogenase activities among the three different depths 0-10cm, 10-20cm and 20-30cm in the disturbed forest (DF) and undisturbed forest (UDF) soils (P≤0.05)

Soil properties	Source of variation	F-ratio	P-level
Fungal population	DF(0-10cm) x UDF(0-10cm)	27.12	$1x10^{-6}$
	DF(0-10cm) x UDF(10-20cm)	66.62	$1x10^{-3}$
	DF(0-10cm) x UDF(20-30cm)	13.99	$2.66x10^{-4}$
	DF(10-20cm) x UDF(0-10cm)	39.02	$1x10^{-3}$
	DF(10-20cm) x UDF(10-20cm)	16.61	$7.6x10^{-5}$
	DF(10-20cm) x UDF(20-30cm)	74.09	$1x10^{-3}$
	DF(20-30cm) x UDF(0-10cm)	16.27	$8.9x10^{-5}$
	DF(20-30cm) x UDF(10-20cm)	34.07	$1x10^{-3}$
Bacterial population	DF(0-10cm) x UDF(0-10cm)	8.36	$4.44x10^{-3}$
	DF(0-10cm) x UDF(10-20cm)	24.27	$2x10^{-6}$
	DF(0-10cm) x UDF(20-30cm)	0	0
	DF(10-20cm) x UDF(0-10cm)	12.56	$7x10^{-6}$
	DF(10-20cm) x UDF(10-20cm)	9.84	$2.07x10^{-3}$
	DF(10-20cm) x UDF(20-30cm)	15.72	$1.16x10^{-4}$
	DF(20-30cm) x UDF(0-10cm)	0	0
	DF(20-30cm) x UDF(10-20cm)	10.26	$5.5x10^{-5}$
Urease activity	DF(0-10cm) x UDF(0-10cm)	0	0
	DF(0-10cm) x UDF(10-20cm)	0	0
	DF(0-10cm) x UDF(20-30cm)	0	0
	DF(10-20cm) x UDF(0-10cm)	0	0
	DF(10-20cm) x UDF(10-20cm)	0	0
	DF(10-20cm) x UDF(20-30cm)	0	0
	DF(20-30cm) x UDF(0-10cm)	0	0
	DF(20-30cm) x UDF(10-20cm)	0	0
Phosphatase activity	DF(0-10cm) x UDF(0-10cm)	4.05	$4.8x10^{2}$
	DF(0-10cm) x UDF(10-20cm)	0	0
	DF(0-10cm) x UDF(20-30cm)	0	0
	DF(10-20cm) x UDF(0-10cm)	0	0
	DF(10-20cm) x UDF(10-20cm)	13.30	$5.06x10^{4}$
	DF(10-20cm) x UDF(20-30cm)	7.36	$8.35x10^{3}$
	DF(20-30cm) x UDF(0-10cm)	0	0
	DF(20-30cm) x UDF(10-20cm)	0	0

Note: *Insignificant values are marked with '0'*

similar variation. However, the soil of the disturbed forest was found to contain more organic C than the undisturbed forest soil. A monthly fluctuation was observed in phosphorus content in both the study sites throughout the study periods (Table 5).

Discussion

Microbial populations

The higher fungal and bacterial populations in the undisturbed forest stand could be due to the availability of the favorable soil moisture, relative high temperature and better availability of organic matter and mineral nutrients. Jha *et al.* (1992) also reported the similar findings. The microbial populations are adversely affected by the disturbance in soil and vegetation. The relatively dense growth of plants and higher accumulation of litter on the forest floor and distribution of fine roots in undisturbed forest favour the growth of microorganisms. Lynch and Whipps (1990) and Wardle (1992) also reported that the organic matter greatly influences the microbial populations. The reduction in fungal and bacterial populations from 0-10 cm to 20-30 cm soil depth may be due to the high organic matter, nutrients status and better aeration in the surface layer and moisture regime (Balasubramanium *et al*., 1972; Selvaraj and Rangaswamy, 1978 and Clarholm and Rosswall, 1980). Tiwari *et al*. (1991) observed decrease in the

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Table 5. Values (range) of physico-chemical characteristics of disturbed and undisturbed forest soils at three different depths 0-10 cm, 10-20 cm and 20-30 cm during the study period of 2002

Forest stands	Depth (cm)	Tempt. (°C)	Moisture Content (%)	pH	Organic Carbon (%)	Total Nitrogen (%)	Available Phosphorus (μg^{-1} dry soil)	Exchangeable Potassium (%)
Disturbed forest	0-10	11.20-18.50	27.97-39.63	5.58-6.46	3.09-6.13	0.52-2.52	11.29-51.39	1.25-5.25
	10-20	10.20-18.00	27.93-37.20	5.94-6.51	2.35-3.96	0.34-1.34	5.33-39.29	1.00-4.63
	20-30	10.10-17.90	29.03-39.70	5.89-6.53	1.92-5.48	0.49-1.18	2.33-25.75	1.00-3.25
Undisturbed forest	0-10	11.40-20.20	19.03-39.20	5.19-6.52	0.82-5.68	0.05-1.93	10.21-59.94	1.13-3.38
	10-20	10.60-20.10	17.20-35.90	5.55-6.21	0.72-3.75	0.19-1.18	4.88-37.29	1.00-3.38
	20-30	10.10-19.40	16-60-36.23	5.59-6.07	0.44-3.48	0.11-0.89	3.99-25.64	0.63-3.00

fungal population with increasing soil depth and related to the organic C content of the soil. The soil moisture content also plays major role in controlling the distribution of microbial populations. Among several factors affecting microbial populations and activity, moisture and nutrient regime and soil depth are important.

Urease activity

Slightly higher urease activity was observed in the disturbed than the undisturbed forest soils. This could be due to the availability of nutrients and other environmental factors like temperature, moisture content and type of vegetation. The similar results were also reported by Pancholy and Rice (1973) and Palma and Conti (1990) who showed that urease activity is related to type of vegetation and the quality of incorporated organic materials in the soil. The enzyme activity showed positive correlation with organic C in the disturbed forest soil. With increase in organic C content, enzyme activities increased. Speir (1977), Beri *et al*. (1978) and Ojeniyi (1980) reported that soil urease activity was largely controlled by the organic C status of the various soils. The positive correlation between urease activity and organic C suggests that the organic C content may be accounted for most of the variations in urease activity (Dalal, 1975 and Tabatabai, 1977; Dkhar and Mishra, 1983). Urease activity decreased with increase in depth. This was also reported by Tiwari *et al*. (1987a); Tiwari (1988, 1996); Dkhar (1983) and Singh (2002). Higher urease activity during the study period in the surface soil may be to due higher organic C content, bacterial population and favorable moisture (Dalal, 1975; Speir, 1977; Tabatabai, 1977; Beri *et al*., 1978; Dkhar and Mishra, 1983; Gonzalez and Fuente, 1984; O'Toole *et al*., 1985; Tiwari et al., 1987b). Sahrawat (1984) noted that urease activity increased with the increasing temperature. Higher urease activity also indicated that it is largely governed by the soil temperature, moisture, organic C. On the other hand, Skujins (1976), Beri *et al*., (1978); Dkhar and Mishra (1983); Sahrawat (1983) and Rao and Ghai (1985) found that the activity was principally associated with the organic C content of the soil. Variations in urease activity were shown to be caused mainly by changes in organic matter content of soils (Bremner and Mulvaney, 1978).

Phosphatase activity

Higher phosphatase activity could be attributed to higher temperature, organic matter and availability of nutrients on the forest floor and also the activity of the plant growth in which enzymes were probably being generated by roots and microorganisms, for these are major sources of phosphatases (Nannipieri *et al*., 1979; Appiah and Thomas, 1982; Chhonkar and Tarafdar, 1984). The increase in phosphatase activity appeared to be related to the leaching of phosphatase from leaf liter and decomposition processes (Brown, 1974). Soil temperature, moisture, organic C, total N and potassium were found to be important factors affecting the phosphatase activity. Singh (2002) also reported similar observations in the degraded and undegraded forests soils of Arunachal Pradesh. The phosphatase activity may be influenced by seasonal and climatic changes in the forest sites. Tiwari (1988) in his investigation reported that phosphatase activity was found to be regulated by the organic C content and soil temperature. The plants and microbes regulate mineralization in

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response to nutrients supply. When nutrients supply is low, enzymes are induced and nutrients are mineralized but when nutrients supply is high, enzymes are suppressed and mineralization ceases. Relationship between nutrient content and enzyme activity is regulated by negative feedback mechanisms. Dilly and Nannipieri (2001) found that the presence of P usually decrease phosphates activity. The phosphatase activity was observed to be higher in the surface soil layer as compared to the layer below it. This could be due to the accumulation of organic matter, pH which enhances the microbial population which in turn increases enzyme activity at the surface soil layer. Similar findings were reported by Trasar-Cepeda and Gil-Sotres (1987); Tiwari (1988; 1996a and b); Tiwari *et al*., (1989a and b); Singh (2000) who showed the decrease in enzyme activity with increase in depth.

Conclusion

From the present study, it can be concluded that the microbial populations and their activities are governed by a set of environmental factors, nutrients status and type of vegetation. However, we did not find any significant positive correlation between the enzyme activities and the fungal and bacterial populations in the two forest stands. It is observed that enzyme activities are influenced by physico chemical characteristics of the soil.

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