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Effects of Anthropogenic Disturbance on Soil Microbial Biomass C, N and P in a Tropical Rainforest Ecosystem of Assam, Northeast India

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ABSTRACT

The effect of anthropogenic disturbance on soil microbial biomass C, N and P dynamics in a tropical rainforest ecosystem of Northeast India was studied in undisturbed, moderately disturbed and highly disturbed stands. Tree species richness in the community was drastically reduced due to disturbance, from 82 species in the undisturbed stand to 13 species in the highly disturbed stand. Soil organic C, total Kjeldahl nitrogen and P concentration was low in the disturbed stands compared to the undisturbed stand. With the increase in disturbance, the microbial-biomass C, N and P decreased significantly (P>0.001) because of lower inputs of organic matter to the soil. Microbial biomass C, N and P ranged between 226-1060 μg g^{-1}, 27-92 μg g^{-1} and 15-52 μg g^{-1}, respectively, in the undisturbed and highly disturbed stands. The seasonal pattern of microbial biomass C, N and P was influenced by the variation of soil moisture and temperature, with maximum during winter and minimum during the rainy season. There were significant positive relationships among microbial biomass C, N and P and SOC, TKN and P concentration. Destruction of above ground vegetation by selective logging and clear felling caused a significant reduction in microbial biomass in the disturbed stands.

Key Words: Disturbance, microbial biomass-carbon, -nitrogen and -phosphorus, soil, tropical rainforest, Northeast India

INTRODUCTION

Micro-organisms play important roles in regulating ecosystem processes such as nutrient mineralisation, soil carbon storage, trace gas fluxes, transformation of aqueous solutes, and processing of water pollutants. Interactions among plants, soil, hydrology and micro-organisms regulate nutrient cycling in ecosystems. These interactions vary in time and space, greatly complicating ecosystem-level assessment of nutrient loss following disturbances and changes in species composition (Vitousek *et al*. 1994). In many ecosystems, soil microbial biomass is closely linked to aboveground plant productivity (Zak *et al*. 1994) suggesting their dependence on inputs of reduced carbon to the soil through litter (Allen and

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Schlesinger 2004).

An understanding of the dynamics of microbial biomass following forest disturbances is important to develop synchronised strategies for reclamation and management of degraded lands. This is particularly critical in the humid tropics where soils are leached and generally nutrient poor. Soil microbial biomass serves as a sensitive indicator of slower, less easily detectable soil organic matter changes and plays an active role in nutrient conservation in the tropical soils (Sarathchandra *et al*. 1984) by preventing leaching of nutrients (Theng *et al*. 1989). Soil microbial biomass responds much more rapidly than the total organic matter to any change in organic inputs (Powlson *et al*. 1987; Cavigelli *et al*. 2005), and its measurement is a valuable tool for understanding and predicting the long-term effects of changes in soil conditions.

Tree cutting is one of the prominent anthropogenic disturbances in the forest ecosystems of Northeast India. Felling results in opening up of the forest canopy that leads to alterations in the forest-floor micro-environment which deteriorates the soil nutrient level. Changes in the soil physico-chemical and microbial biomass due to various disturbances have been studied by different workers in the humid subtropical region of Northeast India (Arunachalam *et al*. 1996; Maithani *et al*. 1996; Arunachalam and Pandey 2003) and in some tropical soils of India (Theng *et al*. 1989). The dynamics of soil microbial biomass is confounded by the vegetal cover that is altered during tree cutting in forests. The seasonal variations in microbial biomass C, N and P and soil physico-chemical properties were determined in order to understand the role of microbial biomass in organic matter and nutrient dynamics in the undisturbed and disturbed stands of a tropical rainforest of Northeast India.

MATERIALS AND METHODS

Study Site

The study was carried out in and around Jeypore Reserve Forest, Dibrugarh Forest Division of Assam (latitude 27°05´- 27° 28´N; longitude 95°20´-95°38´E; altitude 220 m asl on the southern bank of the river Brahmaputra. Champion and Seth (1968) have classified this forest as Assam Valley Tropical Wet Evergreen Forests (I-IB/CI). About two-thirds of the area in the northern side of Jeypore Reserve Forest is more or less flat and the southern side is hilly. The soil of the region can be classified into two classes - old alluvial and new alluvial. The texture of the soil varies from sandy loam to clay loam with 1-5% stones. The area falls within the humid tropical climate with well-pronounced wet summer and winter seasons. Mean monthly temperature varies between 17°C and 36°C. The hottest months are July and August and the coldest months are December and January. The annual rainfall ranges between 2500 and 5000 mm, about 85% of which is received during the wet season. Relative humidity is very high throughout the year.

The present study was carried out in and around Jeypore Reserve Forest. Two disturbed and one undisturbed stand were selected for detailed study. The disturbed stand was divided into two parts on the basis of the disturbance index (Rao *et al*. 1990). Using the ratio of basal area of cut stumps to the total stand

basal area as disturbance index, sites were categorised into moderately (MD, disturbance index of 54%) and highly-disturbed (HD, disturbance index of 88%) stands. The undisturbed stand (*ca*. 2 ha) was in the core area of the Jeypore Reserve Forest. Mature large (>90 cm diameter at breast height) trees of *Dipterocarpus macrocarpus*, *Shorea assamica*, *Mesua ferrea*, *Tetrameles nudiflora*, *Castanopsis indica* and *Vatica lanceaefolia* were abundant in this stand. The moderately disturbed stand was selectively logged (ca. 2 ha) and dominated by *Mesua ferrea*, *Terminalia myriocarpa*, *Alangium begonifolium*, *Tetrameles nudiflora*, *Duabanga grandiflora*, *Sapium baccatum*, etc. The highly disturbed stand (ca. 2.5 ha) was at a distance of about 1 km from the undisturbed stand. It was clear-felled 10 years ago for settled cultivation practices. A few *Biscofia javanica*, *Dillenia indica*, *Duabanga grandiflora*, *Bombax ceiba* and *Albizzia procera were* interspersed in this stand.

Soil sampling

Soil samples were collected from both undisturbed and disturbed forest stands during the months of January, April, July and October that represent winter, spring, rainy and autumn seasons, respectively. From each stand, 20 soil cores (5.5 cm inner diameter) were collected randomly from 0-15 and 15-30 cm soil depths. After removing the litter layer, these were mixed depthwise to obtain composite samples. After removing stones, pebbles and large pieces of plant material, the samples were sieved by 2-mm mesh size sieve and tested for soil physico-chemical and microbial properties. Soil texture, water holding capacity and moisture content were determined according to Anderson and Ingram (1993). Soil organic carbon (SOC) was determined by dichromate oxidation and titration with ferrous ammonium sulphate (Anderson and Ingram 1993). Total Kjeldahl nitrogen (TKN) was estimated following semi-micro Kjeldahl procedure by acid-digestion, distillation and titration. For P concentration, the soil sample was digested using a triacid mixture, followed by colorimetric reaction (molybdenum blue method) with ammonium molybdate and stannous chloride (Jackson 1958). The pH of the soil sample was determined in a soil-water suspension (1:2.5 w/v H_2O) using a digital pH meter.

Microbial Biomass C, N and P

Chloroform fumigation-extraction (CFE) method was used to estimate microbial C (MBC), N (MBN) and P (MBP). MBC and MBN were determined in fresh soil by chloroform-fumigation extraction method (Brookes *et al*. 1985; Vance *et al*. 1987). In the CFE method, a 50 ml beaker containing 15 g fresh soil samples and a 100 ml beaker with 25 ml alcohol-free chloroform were placed in a vacuum desiccator. Another desiccator was maintained without chloroform and both the desiccators were kept under darkened conditions for 72 h at room temperature. Then, the fumigated desiccator was evacuated using a vacuum pump. The soil samples were transferred to a 250 ml conical flask and the fumigated and unfumigated soils were extracted with 200 ml 0.5M K_2SO_4 and kept shaking for 20 min on a rotatory shaker at 110 rpm. The extracts were filtered through a Whatman No. 42 filter paper and the filtrates (10 ml) were digested using H_2SO_4 in a block digestor at 145-155°C for

30 min. The digest was titrated against ferrous ammonium sulphate (0.2N) using 1, 10 phenanthroline monohydrate as indicator. For MBN, the digested filtrate was distilled by steam using a semi-micro Kjeldahl distillation unit and titrated against hydrochloric acid (0.05N). MBP was determined by chloroform fumigation-extraction method (Brookes *et al*. 1982) using 0.5M, NaHCO3 as extracting solution. The MBC, MBN and MBP were calculated as follows: microbial C=(E_C of fumigated soil-E_C of unfumigated soil)x2.64 (Vance *et al*. 1987); microbial N=(E_N in fumigated soil-E_N in unfumigated soil)/0.54 (Brookes *et al*. 1985) and microbial P=(E_P of fumigated soil-E_F of unfumigated soil)/0.40 (Brookes *et al*. 1982) where E_C, E_N and E_F are extractable C, N and P, respectively.

Three-way ANOVA was used to test the effect of season and soil depth on microbial biomass. Correlation and regression tests were applied to study the relationship between microbial biomass C, N and P and soil characteristics (Zar 1974).

RESULTS

The effect of disturbance was more prominent on light intensity, which was several-fold higher for the highly disturbed stand than for the undisturbed stand. Air temperature also showed an increasing trend with an increase in the disturbance level but relative humidity decreased with the increase in disturbance intensity. Soil temperature increased significantly ($P<0.05$) with increasing degree of disturbance. The water holding capacity (WHC) of the soil ranged from 38.18-66.48%; the highest value being in the surface soil layer of the undisturbed stand (66.48%) and the lowest (38.18%) in the subsurface soil layer of the highly disturbed stand. Soil moisture content varied significantly between seasons and soil depths ($F=2.38$; $P<0.05$), though it was invariably higher in the undisturbed stand than the disturbed stands. Soil was acidic in all the stands, but the maximum acidity was recorded in the undisturbed stand. Soil organic carbon (SOC), total Kjeldahl nitrogen (TKN) and P concentration were low in the disturbed stands as compared to the undisturbed stand (Table 1).

Microbial biomass C, N and P decreased with the increase in disturbance intensity from the undisturbed to highly disturbed stand and soil depth (Table 2). The variation in microbial biomass between seasons, soil depths and stands were significant (Table 3). The range of variation in microbial biomass C was 226-414, 320-706 and 513-1060 $\mu g\ g^{-1}$ in the highly disturbed, moderately disturbed and undisturbed stands, respectively. The values were minimum during rainy season and maximum during winter in all the three stands (*Fig. 1*). The microbial biomass N values were 27.36-39.42, 30.96-46.66 and 40.54-92.36 $\mu g\ g^{-1}$ in the highly disturbed, moderately disturbed and undisturbed stands. The surface soil layer had higher microbial biomass N concentration than the subsurface soil layer in all the stands. Marked seasonality in microbial biomass N was recorded in all the stands; it was low during rainy season and high during winter in all the three stands (*Fig.1*). The peak values for microbial biomass P were 52.14, 27.65 and 26.98 $\mu g\ g^{-1}$ in undisturbed, moderately disturbed and highly disturbed stands, respectively. It varied significantly ($P<0.05$) between seasons and soil depths in all the stands. Its seasonal trend in both the soil layers was similar to that of microbial biomass N: maximum during winter and minimum during rainy season (*Fig.1*).

TABLE 1
Vegetation, microclimate and soil characteristics of the undisturbed and disturbed stand

Parameter		Undisturbed	Moderately disturbed	Highly disturbed
Vegetation				
Number of tree species		82	53	13
Tree density (No. ha^{-1})		658	369	41
Tree basal area (m^2 ha^{-1})		85.55	20.83	5.02
Microclimate				
Season				
Light Intensity (Lux)				
	Winter	1005.84±40.61	3816.45±168.67	3694.86 ±492.71
	Spring	2227.60±189.5	8254.83±358.43	18851.80±1193.12
	Rainy	4173.46±308.21	39452.87±366.28	9717.82 ±393.62
	Autumn	1714.85±145.15	5628.42±685.32	7011.80±367.52
Air temperature (ºC)				
	Winter	14.97± 0.4	16.70±0.29	17.5±0.29
	Spring	20.75±0.46	23.70±0.67	25.18±0.41
	Rainy	25.26±0.65	31.10±0.26	31.45±0.58
	Autumn	19.38±0.37	22.62±0.94	23.42±0.70
Relative humidity (%)				
	Winter	58.05±1.98	59.07±1.81	57.07±1.62
	Spring	81.01±1.85	70.23±0.189	63.18±2.23
	Rainy	87.36±3.53	81.43±1.96	69.70±2.23
	Autumn	68.63±0.63	65.29±1.89	63.76±1.76
Soil				
Texture	Soil depth (cm)	Sandy clay loam	Sandy loam	Sandy loam
WHC (%)	0-15	66.48±2.60	52.03±1.44	38.40±2.82
	15-30	64.52±3.72	51.16±2.85	38.18±1.03
Moisture	0-15	29.86±1.91	20.18±1.17	17.96±0.96
content (%)	15-30	28.94±1.73	18.77±0.92	17.43±0.93
pH	0-15	4.95±0.23	5.74±0.15	6.13±0.14
	15-30	5.08±0.19	5.85±0.09	6.36±0.16
SOC (mg g^{-1})	0-15	16.71±0.41	9.50±0.20	7.71±0.80
	15-30	13.90±0.80	7.72±0.52	6.01±0.73
TKN (mg g^{-1})	0-15	6.61±0.30	3.74±0.44	2.53±0.07
	15-30	5.60±0.21	2.91±0.33	2.00±0.40
P (mg g^{-1})	0-15	0.90±0.01	0.73±0.0.02	0.50±0.007
	15-30	0.81±0.02	0.70±0.003	0.45±0.001

SOC-soil organic carbon; WHC- water holding capacity.
The values for the light intensity, air temperature and relative humidity are the mean of each season (±SE; n=5) and rest of the values are the mean of four seasons across the year (±SE; n=20).

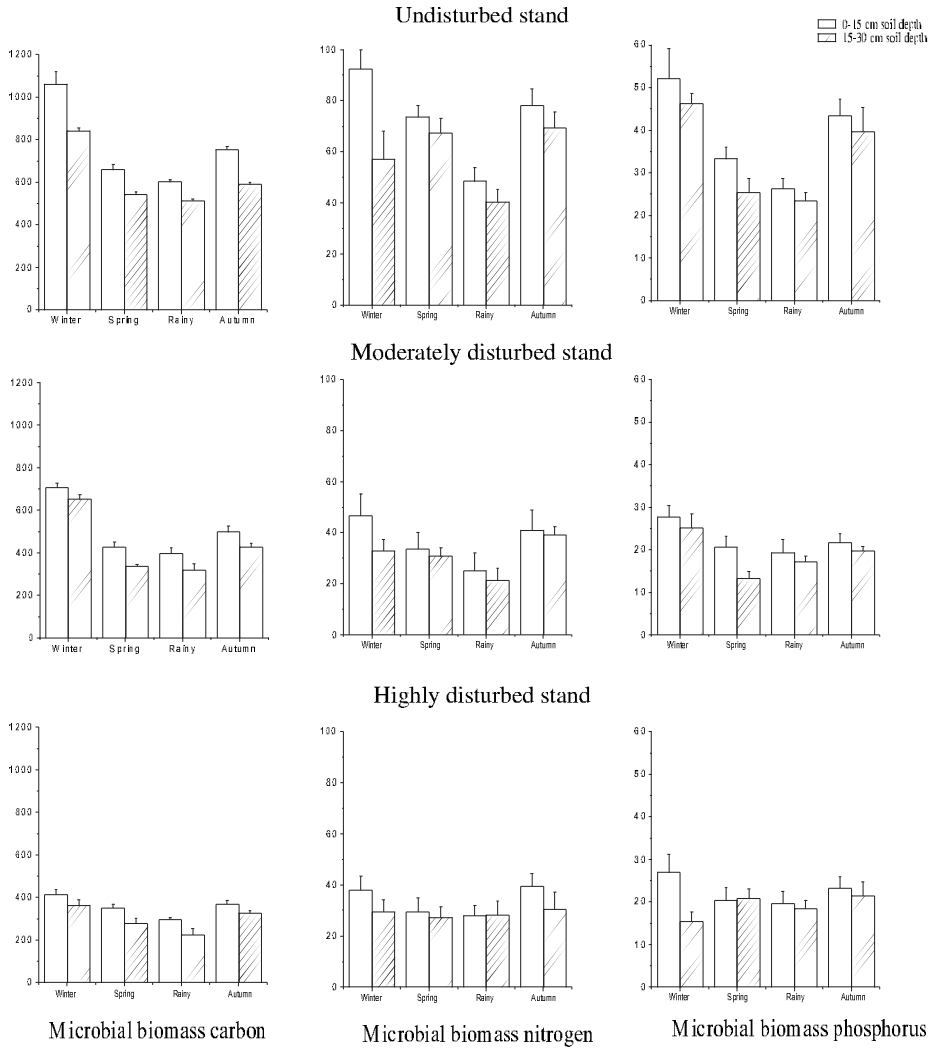

Fig. 1: Seasonal variation in microbial biomass C, N and P ($\mu g\ g^{-1}$) in the undisturbed, moderately disturbed and highly disturbed stands. Vertical lines represent standard error (n=5).

TABLE 2
Mean microbial biomass C, N and P (μg g^{-1}) and their contribution (%) to total soil nutrient (C, N and P) pool in the undisturbed and disturbed stands

Parameter	Soil depth (cm)	Stands		
		Undisturbed	Moderately disturbed	Highly disturbed
MBC	0-15	768.99±53.61	434.40±19.39	357.30±17.15
	15-30	621.45±12.82	330.90±25.33	298.62±22.81
MBN	0-15	72.31±6.04	36.65±7.50	33.83±5.06
	15-30	58.64±7.01	31.15±3.93	28.93±5.24
MBP	0-15	38.82±3.99	22.61±3.19	22.34±2.65
	15-30	33.70±3.35	19.06±2.45	18.86±1.82
MBC/MBN	0-15	10.63	11.85	10.56
	15-30	10.59	10.62	10.32
MBC/MBP	0-15	19.80	19.21	15.99
	15-30	18.45	17.36	15.82
MBN/MBP	0-15	1.86	1.62	1.51
	15-30	1.74	1.63	1.53
Percent contribution				
MBC to SOC	0-15	4.60	4.56	4.63
	15-30	4.47	4.28	4.95
MBN to TKN	0-15	1.09	0.97	1.33
	15-30	1.05	1.07	1.45
MBP to P	0-15	4.31	3.09	4.47
	15-30	4.16	2.72	4.19

± SE (n=20)
MBC- microbial biomass carbon; MBN- microbial biomass nitrogen; MBP- microbial biomass phosphorus; SOC- soil organic carbon

The C: N ratio in microbial biomass (10.56-11.85) was slightly higher in the surface soil layer than in the subsurface layer (10.32-10.62). The microbial C: N ratios were generally low in the lower soil depth than in the upper soil depth in all the stands. The moderately disturbed stand had a higher value than the undisturbed and highly disturbed stands; the latter had the lowest value (Table 2). The microbial N: P ratio varied between 1.51-1.86 and 1.53-1.74 in the upper and lower soil depths. The microbial N: P ratio was higher in the surface soil layer than in the subsurface soil layer in the undisturbed stand, and in the disturbed stands it was high in the lower soil depth (Table 2). The microbial C: P ratio ranged between 15.99-19.80 and 15.82-18.45 in the upper and lower soil depths, respectively. In general, the microbial C: P ratio was greater in the upper soil depth than in the lower soil depth.

The percentage contribution of microbial biomass C to total soil organic C ranged between 4.56-4.63 in the upper and 4.28-4.95 in the lower soil layer. The maximum (4.95%) percentage contribution was in the highly disturbed stand and minimum (4.28%) in the moderately disturbed stand (Table 2). The percentage contribution of microbial biomass N to total Kjeldahl nitrogen varied significantly ($P<0.05$) within the stands and soil depth. In the upper layer, it ranged between

TABLE 3
Three way ANOVA showing effects of season, stand and soil depth on microbial biomass C, N and P ($\mu g\ g^{-1}$)

Variable		MBC		MBN		MBP	
	df	F-ratio	P	F-ratio	P	F-ratio	P
Season	3	64.01	0.001	29.67	0.001	41.65	0.001
Stand	2	291.38	0.001	241.84	0.001	159.51	0.001
Depth	1	34.52	0.001	19.98	0.001	20.49	0.001
Season x depth	3	0.85	0.472	2.30	0.088	1.10	0.057
Season x stand	6	20.67	0.001	7.94	0.001	14.65	0.001
Depth x stand	2	6.99	0.002	8.34	0.001	1.56	0.077
Season x depth x stand	6	2.68	0.052	3.02	0.014	2.65	0.053

df - degree of freedom; P- significant level.
MBC- microbial biomass carbon; MBN- microbial biomass nitrogen; MBP- microbial biomass phosphorus

0.97 and 1.33% and in the lower soil layer, between 1.05 and 1.45%. The highly disturbed stand had the highest proportion of microbial biomass N in soil, while its proportion was minimal in the moderately disturbed stand (Table 2). The contribution of microbial biomass P to total P also varied significantly between seasons and soil depths. The maximum contribution of microbial biomass P to total P was recorded in the highly disturbed stand and minimum in the moderately disturbed stand (Table 2).

DISCUSSION

The undisturbed stand of humid tropical forest was characterised by well-defined vegetation stratification where plants were distributed in four distinct strata. A similar stratification was observed in the moderately disturbed stand with a lower number of tree species. However, in the highly disturbed stand, the stratification was completely disrupted, and only a few tree species were sparsely distributed in the stand. Selective logging and clear felling caused a significant reduction in species richness, density and basal area of trees in the disturbed stands. Disturbance of strong intensity as noticed at the study site was responsible for increasing light intensity and temperature of soil and air in the disturbed stands on one hand, and decreasing relative humidity on the other. Moisture and water-holding capacity of soil became reduced in the disturbed stands due to change in soil texture from sandy clay loam in the undisturbed stand to sandy loam in the disturbed stands.

The chemical characteristics of soil also differed markedly between the undisturbed and disturbed stands. Low soil pH in the undisturbed stand could be the result of greater accumulation of partially decomposed organic matter on the forest floor, while high soil pH in the disturbed stands was due to low accumulation of decomposed organic matter. Significantly greater soil organic C, TKN and P concentration in the undisturbed stand might be due to greater inputs of organic matter through above and below ground litter.

With the increase in disturbance, the microbial biomass C, N and P decreased significantly because of lower inputs of organic matter in the soil. In general,

TABLE 4

Correlation coefficients (r) for the relationship between microbial biomass (μg g^{-1}) and soil physico-chemical parameters (n=20)

Variables	Soil depths (cm)	Moisture content (%)	WHC (%)	SOC (mg g^{-1})	TKN (mg g^{-1})	P (mg g^{-1})
MBC	0-15	0.843**	0.840**	0.917**	0.823**	0.584*
	15-30	0.878**	0.868**	0.927***	0.908**	0.540*
MBN	0-15	0.737**	0.706**	0.824**	0.899**	0.500*
	15-30	0.957***	0.685**	0.867**	0.832**	0.466*
MBP	0-15	0.611**	0.548*	0.778**	0.794**	0.606**
	15-30	0.406*	0.443*	0.653**	0.630**	0.501*

***P< 0.001, **P<0.01, *P<0.05

WHC- water holding capacity; MBC- microbial biomass carbon; MBN- microbial biomass nitrogen' MBP- microbial biomass phosphorus; SOC-soil organic carbon

microbial biomass C, N and P were low during the rainy season when microbial population was large due to favourable temperature and soil moisture condition. Sarathchandra *et al*. (1984) reported that relatively greater demand for nutrients by plants during the rainy season when the majority of them are at their peak vegetation growth further limited the availability of nutrients to soil microbes, thereby reducing their immobilisation in microbial biomass. Other studies in different temperate forest ecosystems have reported that microbial biomass was high in summer during the peak period of photosynthesis and low during winter when the soil was fairly cold (Litton *et al*. 2003; Brant *et al*. 2006). Nonetheless, greater accumulation of litter and fine roots favoured the growth of microbial population and also accumulation of microbial biomass C, N and P in the undisturbed stand. However, a decline in the disturbed stands can be attributed to lower inputs of organic matter in the soil. In the highly disturbed stand, much reduction of microbial biomass C, N and P occurred due to occasional cultivation practices. The decline in the microbial biomass has been reported when natural ecosystems were converted into cultivable lands (Gupta and Germida 1988). The microbial biomass N values (27-92 $\mu g\ g^{-1}$) were lower as compared to the findings reported from coniferous forest (52-125 $\mu g\ g^{-1}$), broadleaved deciduous forest (132-240 $\mu g\ g^{-1}$) and evergreen forest (42-242 $\mu g\ g^{-1}$) (Diaz-Ravina *et al*. 1995; Das *et al*. 1997). This may be due to rapid mineralisation rate confounded by greater microbial activity and N leaching in the tropical soils (Luizao *et al*. 1992). Significant positive correlation between microbial biomass N and soil total N suggests that it can be used as an indicator of soil fertility. Microbial biomass P values (26-52 $\mu g\ g^{-1}$) were, however, well within the reported range (5-67 $\mu g\ g^{-1}$) for woodland soils (Brookes *et al*. 1984). Seasonal changes in microbial biomass P were similar to microbial biomass N. Similar seasonal changes have been reported by Sarathchandra *et al*. (1984) from grassland soils of New Zealand and Arunachalam *et al*. (1996) from humid tropical forest ecosystem of Northeast India. Significant positive correlations between microbial P with organic C (0.778; P<0.01), TKN (0.794; P<0.01) and total P (0.606; P<0.01) show the importance of

soil organic matter as well as TKN and P contents on microbial biomass P (Table 4). In dry tropical soils of India, about 96% of the variability in microbial P could be explained by variability in soil organic P (Srivastava and Singh 1988).

In our present study, significant differences in microbial biomass C, N and P were observed between the surface (0-15 cm) and subsurface (15-30 cm) soil layers. The amount and quality of leaf litter input as well environmental variables are normally considered the main factors affecting surface soil layers. The surface layer is generally a favourable environment for microbes compared to the subsurface soil layer; predation by soil fauna can be also higher (Idol *et al*. 2002). However, reduction in lower soil depth is correlated with low availability of soil organic C and low moisture regime in the soil.

A high microbial C: N ratio indicates greater proportion of fungi, whereas a low ratio indicates a higher proportion of bacteria in the soil metabolism (Anderson and Domsch 1980). The mean C: N ratio (10.32-11.85) in microbial biomass of the three sites was higher than the values (6-9) for various coniferous forest soils (Diaz-Ravina *et al*. 1995), but was similar to disturbed chaparral soils (7-13) reported by Fenn *et al*. (1993). The differences in the form and availability of N may also affect the microbial C: N ratio. The microbial C: P ratios at the three sites were, however, well within the range (14.37-20.72) reported by Brookes *et al*. (1984) from grassland and cultivated fields in the United Kingdom. A wide variation in C: P ratio indicates that the relationship between the two parameters is quite complex (Joergensen *et al*. 1995).

The contribution (4.28-4.95%) of microbial biomass C to soil organic C was greater at the present study sites than in the several other tropical forests (1.5-5.3%) (Theng *et al*. 1989). Maithani *et al*. (1996) have reported 0.7-1.7% contributions by microbial biomass C to soil organic C in selectively felled subtropical humid forests of Northeast India. Arunachalam and Pandey (2003) have reported 2-4.3% contribution in shifting agricultural fields in the humid tropics of Arunachal Pradesh, India. However, contribution of microbial N to total soil Kjeldahl nitrogen was much lower (0.97-1.45%) compared to a range of forest soils (3.4-5.9%) and forest regrowth (7.3-8.3%) (Maithani *et al*. 1996). This might be due to low total Kjeldahl nitrogen in the soil. The percentage (2.72-4.47%) contribution of microbial biomass P to total soil P is comparable with the values reported by Brookes *et al*. (1984) from deciduous woodland (4.7%), grassland (2-4.3%), arable land (1.4-3.5%) and to that of Arunachalam *et al*. (1996) from humid subtropical forest (1.4-4.7%). Nevertheless, significant positive correlations between microbial biomass C, N and P indicate that the dynamics of these three elements are closely interlinked in the tropical soils.

CONCLUSION

In conclusion, felling of trees altered the vegetation and soil physico-chemical characteristics as well as microbial biomass C, N and P, which decreased from low to high disturbance regime. The biomass values were generally low during the rainy season when vegetative growth of plants was at its peak and high during post-rainy periods due to enhanced microbial immobilisation. Further, the microbial biomass C, N and P declined with decreased water holding capacity and concentration of

organic C, total Kjeldahl nitrogen and P in the soil. This indicates the dynamic nature of C, N and P circulation on the forest floor and that the microbial biomass is important for nutrient conservation, regeneration and management of the remnant disturbed tropical forests in the high rainfall area of the Northeast India.

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