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Dynamics of soil biomass C, N, and P in a dry tropical forest in India

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Summary. Three dry tropical forest soils along a topographic sequence were examined to determine the seasonal dynamics of microbial C, N, and P. The lowest microbial biomass was found in forest soils at the foot of the hill followed by midslope forest soils. The hilltop soil, which had the most fine particles, water-holding capacity, organic C, and total N, reflected the presence of greater amounts of microbial C, N, and P. Mean annual microbial C, N, and P ranges were 466–662, 48–72 to 21–30 $\mu g\, g^{-1}$, respectively. The seasonal pattern of microbial biomass, C, N, and P was similar at all sites, the values being greatest during the dry season and lowest during the wet season. The seasonal values for microbial biomass C, N, and P were positively correlated with each other and a negative correlation was found between microbial biomass and the fine root mass in these forest soils.

Key words: Microbial biomass – Dry tropical forest – Seasonal changes – Biomass C – Biomass N – Biomass P

Soil microorganisms, the most active fraction of soil organic matter, play a central role in the flow of C and the cycling of plant nutrients in ecosystems. They constitute a transformation matrix for all the natural organic materials in the soil and act as a labile reservoir for plant-available N, P, and S (Jenkinson and Ladd 1981). Microbial biomass includes the living part of soil organic matter except live root fractions and soil animals larger than 5×10^{-15} m^2 (Jenkinson and Ladd 1981). Immobilization and mineralization of nutrients by and from the soil microbial biomass make a considerable contribution to plant nutrition (Singh et al. 1989; Raghubanshi et al. 1990). Because the microbial biomass affects soil fertility, and hence ecosystem functioning, the measurement of microbial biomass, activity, and nutrient levels is important to the study of soil nutrient cycling. This paper reports the seasonal dynamics of microbial C, N, and P in a seasonally dry tropical forest.

Materials and methods

Study sites

The study area is located on the Vindhyan Plateau in the Marihan range of East Mirzapur Forest Division of Uttar Pradesh, India, at 24° 55′ to 25° 10′ N and 82° 32′ to 82° 45′ E. The area has a seasonally dry tropical climate dominated by a typical monsoon season. The year is divisible into a mild winter (November-February), a hot summer (April–June), and a warm rainy season (July–September). October and March are transitional months between the rainy season and the winter, and between winter and summer, respectively. The summer is dry and hot, with temperatures ranging between 30° and 45 °C during the day (Fig. 1). During the winter, temperatures fall to 10–25 °C and January is the coldest month of the year. The annual rainfall averages 820 mm, 86% of which arrives with south-west monsoons during the rainy season. In the annual cycle, there is an extended dry period of about 9 months. There are often long breaks in rainy days, even during the wet season, and July and August are the wettest months.

Red-coloured fine-textured sandstone (Dhandraul orthoquartzite) is the dominant rock in this area. It is generally underlain by shale and limestone. The soils are Ultisols (hyperthermic typic Plinthustults with Ustorthents, according to the VII approximation of the USDA soil nomenclature).

Three forest sites were selected along a topographic sequence, the first site located on the footslope of the hill, the second midslope, and the third on the hilltop. Large boulders and pebbles occur in the hilltop and midslope positions; 28% of the hilltop and 30% of the midslope are covered with rock outcrops and large boulders. The soil depth at these two sites is variable and averages 15 cm. The footslope site has depositional soil with no rock outcrops and the soil depth frequently exceeds 1 m.

In the footslope site, the depleted natural forest cover has been enriched by the State Forest Department with plantations of *Acacia catechu* and *Emblica officinalis*, which comprise the top storey. The second stratum comprises small tress of *Ougeinia oojeinensis* and the shrubs *Ziziphus glaberrima*, *Ziziphus oenoplia*, and *Carissa opaca*. The midslope site is dominated by *Acacia catechu* and *Lannea coromandelica* in the top layer, with the understorey dominated by the shrubs *Nyctanthes arbor-tristis*, *Holarrhena antidysenterica*, and *Ziziphus glaberrima*. The top storey of the vegetation on the hilltop is dominated by *Boswellia serrata* and *Acacia catechu*, with *Nyctanthes arbor-tristis* and *Ziziphus glaberrima* dominating the understorey. The total forest basal cover (trees+shrubs) was 8.7 m^2 ha^{-1} on the footslope site, 11.6 m^2 ha^{-1} on the midslope, and 14.8 m^2 ha^{-1} on the hilltop site (Singh and Singh 1991).

Sample collection

From each site five samples (each about 250 g) were collected randomly from the upper 10 cm soil layer in the rainy, winter, and summer seasons of the June 1988 to June 1989 annual cycle. Large pieces of plant material were removed and the samples were sieved through a 2-mm mesh screen. While Jenkinson and Powlson (1980) and Ross et al. (1985) found little difference in the biomass C content of sieved and unsieved samples, Ross et al. (1985) recommended sieving for soils, particularly in systems where the quantity of roots in individual cores is highly variable. In the present study, sieved samples were composited for each site, and from this composite stock three subsamples were drawn for further analysis. Air-dried soil samples were analysed for texture, organic C, total N, and P. All results are expressed on an oven-dry soil basis.

Soil characterization

The particle-size distribution (texture) was analysed by using sieves of different mesh sizes and the pipette method (Piper 1944). Soil pH was determined by using a glass electrode (1 : 2, soil : water ratio). The bulk density and walter-holding capacity was determined by methods described in Piper (1944). Total C and N were determined with a Perkin-Elmer CHN Autoanalyser and organic C was calculated by subtracting the inorganic C content (Jackson 1958) from total C. Total P was measured colorimetrically after $HClO_4$ digestion (Jackson 1958). NO_3^--N was measured by a phenol disulphonic acid method, using $CaSo_4$ as the extractant (Jackson 1958). NH_4^+-N was extracted by 2 *M* KCl and analysed by the phenate method (American Public Health Association 1985). $NaHCO_3$-P_i was determined by an ammonium molybdate-stannous chloride method (Jackson 1958).

Microbial biomass C analysis

Field-moist samples were preincubated for 7–10 days at room temperature (25°–28 °C) to equilibrate the respiration. Soil microbial biomass C was determined by the $CHCl_3$ fumigation-incubation method of Jenkinson and Powlson (1976), except that liquid $CHCl_3$ was used instead of vapour, and the CO_2-C evolved from the fumigated soil over 10–20 days was taken as the control level (Srivastava and Singh 1988). With this method, 100-g samples of soil were saturated with purified liquid $CHCl_3$ for 18–20 h and the $CHCl_3$ was subsequently removed by placing the samples overnight in an oven at 40 °C (Srivastava and Singh 1988). The samples were then inoculated with 1 g unfumigated soil from the respective stock and adjusted to 50% – 60% water-holding capacity. The samples were subsequently held at 27±2 °C in airtight and leak-proof aluminium cabinets, each with two beakers, one having 50 ml 1 *N* NaOH and the other 20 ml distilled water to counter the drying effect of the alkali. The CO_2 evolved from the fumigated, incubated soil was measured by titrating the residual alkali. Microbial C was calculated as $X-Y/k_C$ where X is the CO_2-C evolved from fumigated soil over 0–10 days, Y is the CO_2-C evolved from fumigated soil over 10–20 days, and k_C is the fraction of biomass C mineralized in the first 10 days of incubation after fumigation of the soil. A k_C value of 0.45 was used (Jenkinson and Ladd 1981).

Microbial biomass N analysis

Biomass N was determined on the same field-moist soil stock from which biomass C was determined, using the $CHCl_3$ fumigation extraction method (Brookes et al. 1985). In brief, 25 g field-moist sample was saturated with purified liquid $CHCl_3$ for 18–20 h. After fumigation the soil was extracted with 0.5 *M* K_2SO_4 (1 : 4, soil : extractant) for 30 min. Unfumigated soil was also extracted in the same way. The soil extracts were analysed for total N using the Kjeldahl digestion procedure. The flush of total N (K_2SO_4-extractable N in unfumigated soil subtracted from that of fumigated soil) was divided by a k_N (fraction of biomass N extracted after $CHCl_3$ fumigation) value of 0.54 (Brookes et al. 1985; Srivastava et al. 1989).

Microbial biomass P

Biomass P was also determined by the $CHCl_3$ fumigation extraction method (Brookes et al. 1982; Srivastava and Singh 1988). A 5-g sample of field-moist soil was taken in a 250-ml conical flask and saturated with liquid $CHCl_3$ for 18–20 h. In this analysis, $CHCl_3$ was not removed because its presence prevents microbial growth during extraction and filtration (Brookes et al. 1982). Microbial P was calculated by dividing the flush of P_i ($NaHCO_3$-P_i in fumigated soil minus that in unfumigated soil) by a k_P value of 0.40, as recommended by Brookes et al. (1982) and used by Srivastava and Singh (1988). Biomass P was corrected for P fixation during the $NaHCO_3$ extraction by measuring the recovery of a spike of added P_i as KH_2PO_4 (equivalent to 20 µg P per g soil; Brookes et al. 1982).

Fine root biomass

The seasonal fine root biomass (< 5 mm diameter) was determined by using 10 monoliths (15×15×15 cm) on each site. The monoliths were washed with a fine jet of water and collected on a 0.5-mm mesh screen. The roots were oven-dried at 80 °C to a constant weight.

Results and discussion

Results of the physico-chemical analyses of the soils are given in Table 1. The texture was sandy loam, with bulk density ranging from 1.37 to 1.68. The soil from the footslope site had the highest bulk density and that from the hilltop site the lowest. Organic C, total N, and total P ranged from 0.47 to 2.0, 0.05 to 0.16, and 0.021 to 0.031%, respectively. In these forest soils, the highest concentrations of soil organic C, total N, and total P occurred in the hilltop site, followed by the midslope site. The pool sizes for inorganic N (NO_3^--N+NH_4^+-N) and $NaHCO_3$-P_i were highest during the dry periods of the annual cycle.

Within the annual cycle, microbial C ranged from 341 to 872 µg g^{-1} dry soil. Microbial C was highest in the hilltop soil ($\bar{X}$ = 662 µg g^{-1}), and lowest in the footslope soil ($\bar{X}$ = 466 µg g^{-1}). Microbial biomass N ranged from 38 to 78 µg g^{-1}, with a maximum in the hilltop soil and a minimum in the footslope soil. During the study period, microbial P in these forest soils ranged from 17 to 40 µg g^{-1}, the footslope site recording the lowest and the hilltop site the highest values. There were significant differences among the soils in biomass C, N, and P ($P<0.05$). Although little information is available from the tropics on the effect of topographic positions on microbial biomass values, Livingston et al. (1988) recently showed that microbial N in an Amazonian forest varied from 27.9 to 119.6 µg g^{-1}, with ridgetop soils showing maximum and footslope soils minimum values. In the present study the hilltop soil, which had the largest percentage of fine particles, water-holding capacity, organic C and total N, also contained greater amounts of microbial C, N, and P.

Mean annual microbial biomass C, N, and P values in the present study ranged from 466 to 662, 48 to 72, and 21 to 30 µg g^{-1} dry soil, respectively (Table 2). Biomass C as a proportion of soil organic C ranged from 3.3 to 5.7%, with one exceptional value of 9.9% in the footslope site, due to a very low level of soil organic C. For certain Indian tropical soils, Srivastava and Singh (1988) reported 2.5% to 5.6% soil organic C as biomass C. In the pre-

Table 1. Physico-chemical characteristics of forest soils

		Footslope	Midslope	Hilltop
Bulk density ($g\,cm^{-2}$)		1.68 ± 0.002	1.48 ± 0.003	1.51 ± 0.02
Fine particles (% silt + clay)		31 ± 1.2	37 ± 1.4	44 ± 1.7
Water-holding capacity (%)		38 ± 0.3	44 ± 1.7	46 ± 1.5
pH (H_2O)		6.3 ± 0.06	6.2 ± 0.04	6.2 ± 0.09
Organic C (%)		0.47 ± 0.07	0.98 ± 0.09	2.00 ± 0.09
Total N (%)		0.05 ± 0.01	0.09 ± 0.01	0.16 ± 0.02
Total P (%)		0.021 ± 0.000	0.025 ± 0.001	0.031 ± 0.003
Inorganic N ($\mu g\,g^{-1}$)	Rainy	3.33 ± 0.81	3.75 ± 0.45	4.25 ± 0.85
	Winter	3.63 ± 0.09	3.66 ± 0.43	3.86 ± 0.53
	Summer	5.07 ± 0.42	5.44 ± 0.38	5.34 ± 0.49
$NaHCO_3$-P_i ($\mu g\,g^{-1}$)	Rainy	0.86 ± 0.41	1.47 ± 0.14	1.55 ± 0.27
	Winter	1.01 ± 0.13	1.07 ± 0.12	1.26 ± 0.12
	Summer	3.14 ± 0.10	3.08 ± 0.23	3.62 ± 0.19

Means ± SE

sent study, biomass N as a proportion of total soil N ranged from 4.5% to 9.6%. Microbial N generally accounts for 2% to 6% of the total soil N (Dalal and Mayer 1987), but for tropical *Shorea robusta* forest and grass savanna ecosystems, Srivastava et al. (1989) reported 3.6% to 4.8% soil organic N in the microbial biomass. For a range of Pakistani soils, these values varied between 2.6% and 14.8% (Azam et al. 1989). In the present study, biomass P as a proportion of total soil P averaged 9.4% to 10.2% (Table 2). An earlier study on a range of Indian soils showed that microbial biomass P accounted for 9% to 19% of the total soil organic P (Srivastava and Singh 1988). Thus the present values are within the range of values reported for other soils.

The present study yielded strong positive relationships among microbial C, N, and P. Seasonal values of microbial C, N, and P were related according to the following regression equations:

Microbial N = 2.87 + 0.10 (microbial C)
($r^2 = 0.97$, $P < 0.001$)

Microbial P = 2.10 + 0.041 (microbial C)
($r^2 = 0.95$, $P < 0.001$)

Microbial P = 1.20 + 0.40 (microbial N)
($r^2 = 0.95$, $P < 0.001$)

where microbial C, N and P values are in $\mu g\,g^{-1}$ dry soil.

In a study on a broad range of soils, Brookes et al. (1984) also found a linear relationship between biomass P and biomass C. This relationship explained 81% of the variability in biomass P by the variability in biomass C. For a range of six Indian tropical soils, Srivastava and Singh (1988) found that 78% of the variability in biomass P could be explained by the variability in biomass C. As in the present study, Srivastava et al. (1989) found a direct positive relationship between biomass C and N ($r = 0.92$, $P < 0.01$), and between biomass N and biomass P ($r = 0.98$, $P < 0.01$).

Table 2. Mean annual soil biomass in forest soils

	Footslope	Midslope	Hilltop
MB-C ($\mu\,g^{-1}$)	466	556	662
MB-N ($\mu\,g^{-1}$)	48	62	72
MB-P ($\mu\,g^{-1}$)	21	25	30
MB-C/organic C	9.9	5.7	3.3
MB-N/total N	9.6	6.9	4.5
MB-P/total P	10.2	9.8	9.4
MB-C/MB-N	9.7	9.0	4.5
MB-C/MB-P	22.2	22.2	21.1

MB-C, microbial C; MB-N, microbial N; MB-P, microbial P

In the present study, the biomass C:N ratio ranged from 9.0 to 9.7. Dalal and Mayer (1987), studying Australian arable soils, reported a biomass C:N ratio of 8.7 to 13.2, and for soils under a *Shorea robusta* forest, Srivastava et al. (1989) reported a C:N ratio of 10.6 to 11.6. Most of the studies in temperate ecosystems show a smaller biomass C:N ratio, ranging from 3.8 to 6.1 (Schimel et al. 1985; Powlson et al. 1987). Sarathchandra et al. (1984) found that the biomass C:P ratio for New Zealand pasture soils ranged from 15 to 63. Later, two of the biomass C:P ratios of Sarathchandra et al. (1984) were judged unusual and were excluded, giving a range of 15 to 36 (Brookes et al. 1984). Thus, a C:P ratio of 22.1 to 22.2 in the present study is in accord with published values and is within the range, 17 to 30, reported for other Indian soils (Srivastava and Singh 1988; Srivastava et al. 1989). Brookes et al. (1984) and Dalal and Mayer (1987) argued that variations in the biomass C:N and C:P ratios under different conditions may not always be comparable, because the proportions of microbial N and P mineralized (k_N and k_P values) may vary (Ross et al. 1987).

The seasonal pattern of soil microbial C, N, and P was similar at all sites, with maximum values during the dry season and minimum values during the wet season (Fig. 2). These seasonal differences in microbial C, N, and P were significant at $P < 0.05$. It is possible that the usual burst of CO_2 following adjustments in the moisture content of the relatively dry soils of the summer season might have contributed to the high biomass value estimated for that season. However, since microbial N and P were also higher in the summer samples, the seasonality effect appears to be real. Literature on the effect of seasonality on the biomass is limited. Studies in temperate pasture soils have shown a seasonal pattern of high

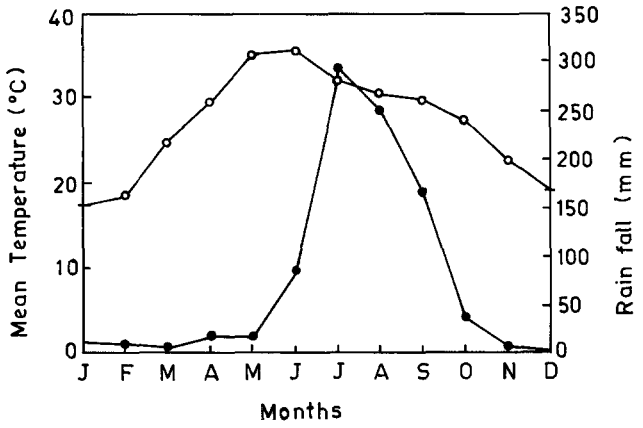

Fig. 1. Temperature and rainfall diagram for the study area based on data for 8 years (1982–1989). *Solid circles* represent rainfall and *open circles* monthly mean temperature

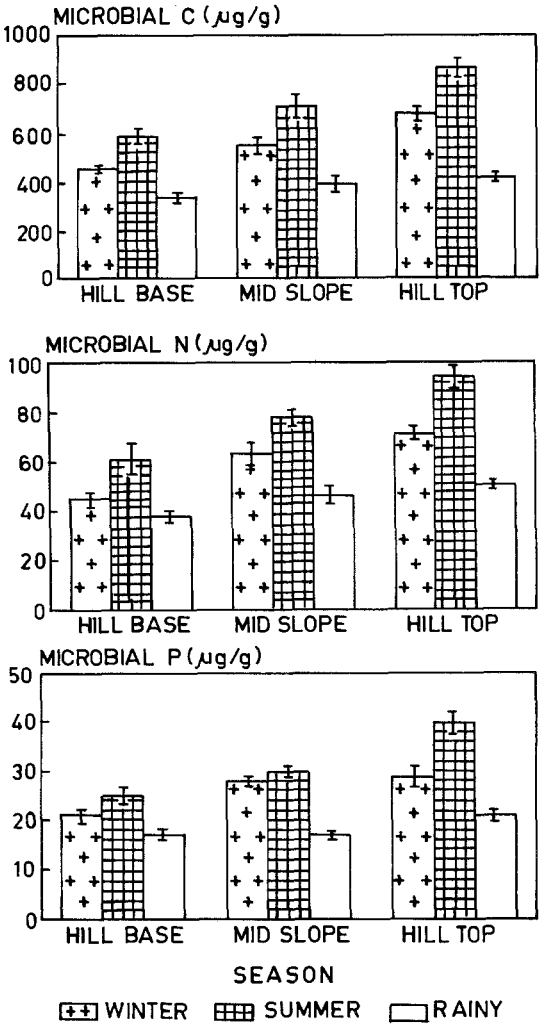

Fig. 2. Seasonal variation in microbial biomass C, N, and P in forest soils (bars ± SE)

autumn-low winter-high spring values of microbial biomass C (Lynch and Panting 1982; Ross et al. 1984; Sarathchandra et al. 1988). Sarathchandra et al. (1988) reported an accumulation of biomass N and P over winter and a decline in spring. In their study the highest biomass C was measured in the driest sample collected. Ross et al. (1984) also reported high biomass C values in dry soil samples collected in the late autumn, and suggested that an increase in the fungal populations decomposing dead roots, etc., at lower water potentials might explain the high biomass levels. Fungal spores and mycelial fragments survive under very low soil moisture levels (Griffin 1969), due to protection from desiccation by being associated with soil organic matter (Warcup 1957). Many non-spore-forming species may also persist for months in dry soils (Chen and Alexander 1973). Shields et al. (1973) reported an increase in the ratio of fungal C to bacterial C as soil moisture decreased.

Studies of the temporal dynamics of N mineralization in the present and adjacent sites have indicated that a net immobilization of N occurs during the summer months when the soil is dry (Singh et al. 1989; Singh et al. 1991). The microbial communities of droughty soils (soils with high water deficits) are preadapted to moisture stress (Sparling et al. 1987) and the activity of mineralizing microbes may continue at high moisture tensions (Semb and Robinson 1969). West et al. (1988) reported that the microbial mass in soils with the lowest rainfall in an Australian climosequence showed the greatest resistance to desiccation.

The rainy season decrease in the levels of microbial biomass in the present study was probably due to cell lysis as the dry soil of summer was wetted by intense rains. It is possible that we might have missed a transient increase in biomass due to the release of substrate for microbial metabolism when the dry soil was wetted, because our sampling was less frequent. However, studies show that the increase in soil nutrients due to drying and subsequent rewetting are largely derived from the mineralization of dead microbial cells (Marumoto et al. 1977; Sparling and Ross 1988). Disruption of the soil structure could also enhance the availability of the substrate (Van Veen et al. 1985). In soils with wet and dry seasons, an increased water potential may cause a seasonal turnover of microbial biomass by inducing microbial plasmoptysis, by which all cellular constituents, including N and P, are released (Keift et al. 1987). Enhanced microbivore populations during the rainy season may also decrease the microbial biomass and lead to a faster turnover (Singh et al. 1989).

In the present study, seasonal microbial biomass values were negatively correlated with seasonal fine root mass values according to the following equations:

$$\text{Microbial C} = 1213.9 - 172.2 \text{ (fine root)} \quad (r^2 = 0.68,\ P < 0.006)$$

$$\text{Microbial N} = 118.8 - 14.8 \text{ (fine root)} \quad (r^2 = 0.59,\ P < 0.015)$$

$$\text{Microbial P} = 370.3 - 7.2 \text{ (fine root)} \quad (r^2 = 0.75,\ P < 0.003)$$

where microbial C, N, and P values are in kg ha^{-1} and fine root values are in t ha^{-1}.

Most studies on the effect of plant roots on microbial biomass are based on a comparison of planted soils with

an unplanted one. Bottner et al. (1988) have reported a lower microbial biomass in planted soils during the first 150 days and a higher microbial biomass during the latter periods of the experiments. However, Klemedtsson et al. (1987) did not detect any significant change in microbial biomass C when soils were planted with barley. Van Veen et al. (1989) speculated that plants have dual, opposing effects on microbial activity in the soil, by stimulating microbial activity through the supply of organic substrate on one hand, and by limiting microbially mediated processes, through depletion of mineral nutrients, on the other hand. In nutrient-poor soils, the microbial nutrient supply may severely limit microbial use of materials released from roots. In these soils plants will compete for mineralized nutrients, and reduce the chance of an effective biomass growth (Van Veen et al. 1989).

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