



Effects of land-use change on soil microbial C, N and P in a Himalayan watershed

P. Sharma^a, S.C. Rai^{a,*}, R. Sharma^b, E. Sharma^c

^aG.B. Pant Institute of Himalayan Environment and Development, North-East Unit, Vivek Vihar, Itanagar-791113, Arunachal Pradesh, India

^bCentre for Environmental and Agricultural Policy Research, Extension and Development, Kathmandu, Nepal

^cMountain Farming Division, International Center for Integrated Mountain Development, Kathmandu, Nepal

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Summary

Soil microbial C, N and P as affected by land-use change were studied in a Himalayan watershed at Sikkim, India. The major land-uses considered were forests (dense and open), agroforestry types (large cardamom and mandarin), open cropped and wasteland areas covering subtropical and temperate zones. Across the land-use, microbial C ranged from 219 to 864 $\mu\text{g g}^{-1}$, microbial N from 30 to 142 $\mu\text{g g}^{-1}$, and microbial P from 12 to 43 $\mu\text{g g}^{-1}$ soils. The microbial C, N and P were positively related to each other. The microbial C:N ratio in these soils ranged from 6 to 11 and the microbial C:P ratio from 18 to 27. The conversion of forests into other land-uses resulted in a remarkable decline in the amounts of soil nutrients and microbial C, N and P. The microbial nutrients in the Himalayan region are very sensitive to land-use/cover changes. Therefore, the conversion of forest to agricultural land should be reversed. Agroforestry systems should be included in agricultural land in mountainous regions.

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Introduction

Conversion from forest to agricultural land strongly impact soil nutrients and microbial biomass depending on the type of land-use change and the post conversion land management. The land-use change from forest to other usage has been conspicuous over the past two decades, causing

depletion of natural resources in the Sikkim Himalaya (Rai et al., 1994). Forest-dominated watersheds are converted into agrarian watersheds. Cultivation leads to a considerable loss of soil organic matter and microbial biomass (Bauer and Black, 1981; Srivastava and Singh, 1989; Luizao et al., 1992; Henrot and Robertson, 1994).

*Corresponding author. Tel./fax: +91-360-2211773.
E-mail address: raisc1958@rediffmail.com (S.C. Rai).

Soil microbial biomass constitutes a transformation matrix for natural organic materials in soil and act as a labile reservoir of plant available nutrients (Jenkinson and Ladd, 1981; Singh et al., 1989; Srivastava and Singh, 1991). The microbial biomass component of soil organic matter is a sensitive indicator of organic matter dynamics because the microbial fraction changes comparatively rapidly, and differences are detectable before they occur in total organic matter (Powlson and Jenkinson, 1981; Powlson et al., 1987). Thus measuring microbial biomass is a valuable tool for understanding and predicting long-term effects of changes in land-use and associated soil conditions.

Changes in soil organic matter contents following land transformation are recognized issues in the global C balance debate and also for assessing long-term sustainable land-use (Sparling et al., 1994). No data are available on changes in soil microbial C, N and P as a consequence of land-use change in the Himalayan region. Therefore, the aims of the present study are to assessable impact of land-use change on C, N and P contents in soils and soil microbial biomass of forests, agroforestry systems, agriculture land and wastelands.

Materials and methods

Study area

This research was carried out in Mamlay watershed, which is located in the southern part of Sikkim state in the eastern Himalayan biogeographic zone (Fig. 1). It lies in between 27°10'8" to 27°14'6"N and 88°19'53" to 88°24'43"E at 300–2650 m, asl. The watershed lies entirely in the mountainous zone. The area is typified by folded structure and varied lithology with older rocks occupying the upper structural levels. It bears the evidences of two persistent thrusts viz., the Sikkim and the Tendong (Sharma et al., 1992).

The climate of the watershed is monsoonic and the average rainfall varied from 1200 mm at 800 m to 3000 mm at 1900 m during 1999–2000, most of which occurred in the rainy season during June to September. The average maximum temperature in temperate belt (1900 m) was 18°C while the minimum temperature reached upto 11°C. The subtropical belt (800 m) of the watershed experienced mean maximum temperature of 30°C and minimum of 15°C. The humidity remains high particularly at higher ridges. The terrain is hilly with steep slopes (30–40°).

Land-use change

The land-use change of the Mamlay watershed was quantified by surveys. For the first survey conventional data were collected (Rai and Sharma, 1998). Satellite imageries, IRS 1A/1B, LISS-II, and IRS 1C, LISS-III, FCC bands 2, 3, and 4 in the scale of 1:50,000 were used in combination with the India topographical map. Intensive field investigations were carried out for verification.

The land-use data generated through satellite imagery has been classified into four major classes viz., forests (dense and open), agroforestry systems (large cardamom and mandarin), agricultural lands and wastelands covering subtropical and temperate zones. The land-use pattern in the watershed as a whole showed about 14% and 31% area under agricultural practices in 1988 and 2001, respectively. The agroforestry practices in the watershed are traditional and about 4% area came under these practices in both the years. The total forest land in the watershed accounted for 69% and 49% of the total area and wasteland covered about 11% and 15% in 1988 and 2001, respectively.

The land-use change detection was generated by the multi-date satellite data (Rai and Sharma, 1998). Monitoring of land-use reflected that changes were greater in extent over the span of 13 years (1988–2001) in the land under different categories. The most dramatic changes are the increase in agricultural area and decrease in forest cover area. The open cropped area increased by more than 100% for the 13 years period, while wasteland increased by about 149%. The total forest cover (temperate natural forest dense, temperate natural forest open and subtropical natural forest open) decreased by 28% during 1988 to 2001. Ground-truth information supports the finding that depletion of closed forest or its conversion into other categories is the result of maximum anthropogenic pressure on the limited forest resources.

Sampling and analysis

Twenty-seven sites from nine dominant land-use types were selected for the study covering slope and altitude, i.e., three forest types (dense mixed, open mixed and degraded), two agroforestry systems (cardamom based and mandarin orange), two rainfed crop fields (temperate and sub-tropical), and two wastelands (wasteland temperate and wasteland sub-tropical) (Table 1). All sites were located within a geographic distance of <3 km in a designated watershed area.

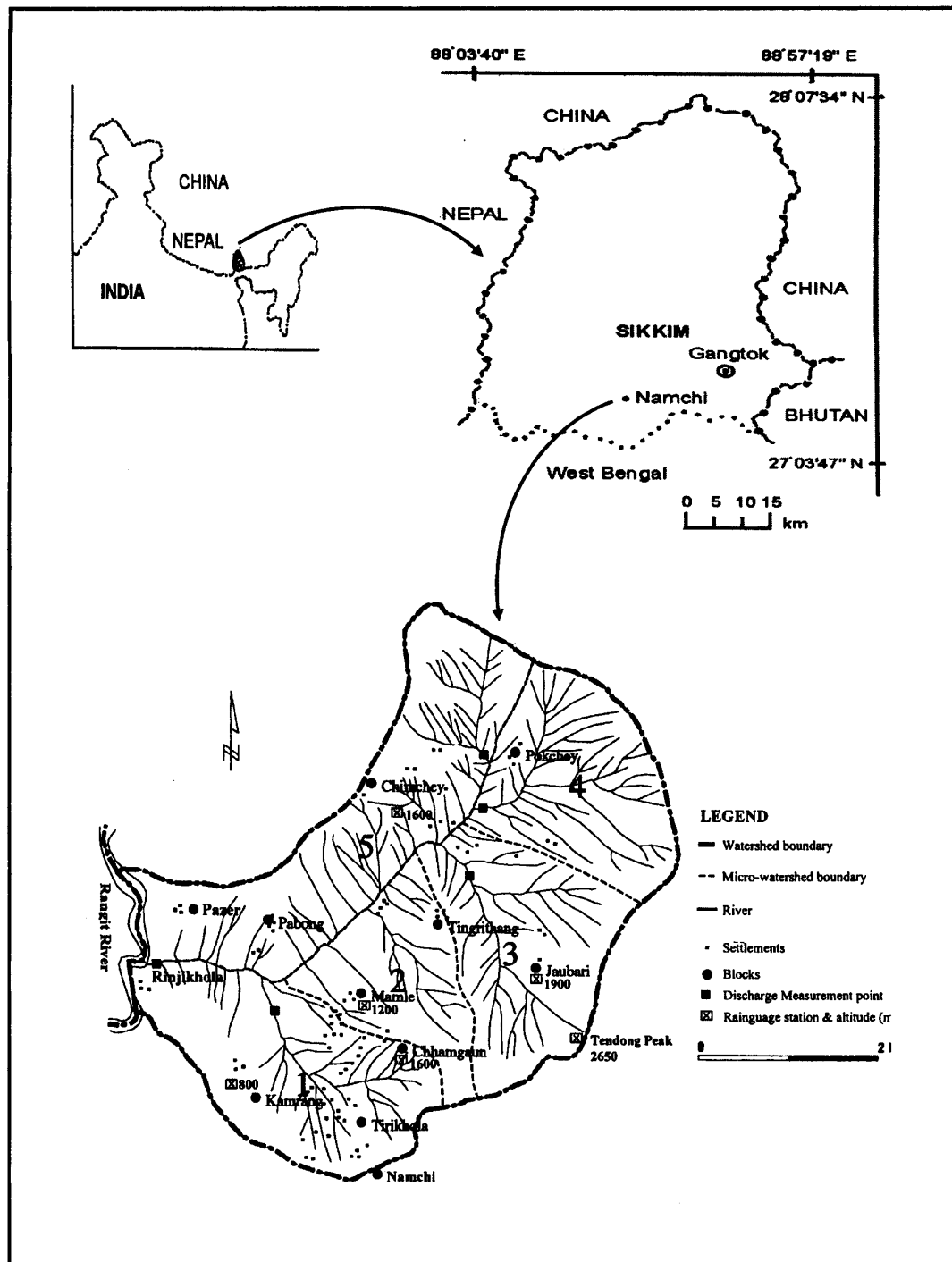


Figure 1. Location map of the Mamlay watershed showing drainage pattern and settlements.

Table 1. Site characteristics and physicochemical characteristics of soil

Land-use	Altitude (m)	Slope (deg)	Soil texture	Bulk density (cm)	Soil pH	Moisture content (%)	Total organic C ($\mu\text{g g}^{-1}$)	Total N ($\mu\text{g g}^{-1}$)	Total P ($\mu\text{g g}^{-1}$)
Temperate natural forest dense	1900–2650	30–52	Sandy loam	1.31	5.10 \pm 0.10	33.5 \pm 5.2	32 \pm 4.3	2.84 \pm 0.70	0.83 \pm 0.16
Temperate natural forest open	1000–2650	35–42	Sandy loam	1.17	5.02 \pm 0.07	30.3 \pm 5.1	26 \pm 1.3	2.47 \pm 0.71	0.66 \pm 0.11
Subtropical natural forest open	300–1000	30–35	Silty loam	0.64	5.16 \pm 0.05	20.2 \pm 4.1	15 \pm 2.0	2.38 \pm 0.60	0.65 \pm 0.12
Cardamom based agroforestry	1600–1900	25–30	Silty/clay loam	0.89	5.44 \pm 0.04	28.9 \pm 3.4	22 \pm 1.5	2.30 \pm 0.64	0.76 \pm 0.13
Mandarin based agroforestry	400–1600	20–25	Silty loam	0.84	6.11 \pm 0.18	16.6 \pm 3.3	14 \pm 2.1	1.90 \pm 0.36	0.70 \pm 0.15
Open cropped area temperate	1000–2000	25–30	Sandy loam	0.57	6.43 \pm 0.04	27.8 \pm 4.2	22 \pm 1.0	2.00 \pm 0.55	0.75 \pm 0.09
Open cropped area subtropical	300–1000	20–25	Sandy loam	0.46	6.02 \pm 0.10	17.1 \pm 3.1	13 \pm 1.6	2.05 \pm 0.41	0.70 \pm 0.09
Wasteland area temperate	1000–2000	25–30	Sandy silt	0.72	5.21 \pm 0.05	26.4 \pm 3.7	17 \pm 3.3	2.00 \pm 0.48	0.46 \pm 0.09
Wasteland area subtropical	300–1000	20–25	Sandy soil	0.76	5.90 \pm 0.16	16.5 \pm 3.8	12 \pm 0.4	1.50 \pm 0.33	0.47 \pm 0.10

Soil sampling was carried out in replicates from the marked sample plots at each of the nine selected land-use from 0–15 cm depth. Large pieces of plants and stones were removed and the soils were sieved through 2mm mesh screen. Each sample was divided into two parts. One part in the field moist condition was used to determine microbial C, N and P, and the other part was air dried for the rest of the analyses. All data reported are means for three seasons (winter, short summer and rainy), three replicate sites of each land-use and 2 years (1999–2000 and 2000–2001).

Soil texture was analyzed by using soil sieves of different mesh sizes (Anderson and Ingram, 1993). Soil pH was measured by mixing 10g of fresh soil in 50ml distilled water for 30min and using a glass electrode digital pH meter. Soil organic carbon was estimated using the modified Walkley–Black method and total nitrogen by modified Kjeldahl method (Anderson and Ingram, 1993). The phosphorus was determined colorimetrically. Total phosphorus was extracted using acidified ammonium fluoride after oxidation; Employing 30% H_2O_2 and estimated by chlorostannous-reduced molybdophosphoric blue color method (Jackson, 1967) and the difference between total p and inorganic p in the extract before and after oxidation of the organic matter represents organic P (Jackson, 1967).

All soils were analyzed for microbial C, N and P. Sieving could have some effect on biomass determination (Lynch and Panting, 1981), however, the samples in the field-moist soils were stored for 7 days, without adjusting the soil moisture at room temperature (25–28°C) to allow the respiration to recover (Srivastava and Singh, 1988). Soil microbial biomass C was determined using CHCl_3 fumigation–incubation method after Jenkinson and Powlson (1976) except that liquid CHCl_3 was used instead of vapor (Srivastava and Singh, 1988). For microbial biomass carbon and nitrogen analyses, two sub-samples of 10 \pm 0.01g were weighed into 150ml beaker and the first sub-sample was extracted with K_2SO_4 . This extract was analyzed for dissolved organic carbon (Ct_0). The second sub-sample was fumigated with 30ml alcohol-free liquid chloroform. The chloroform was evaporated applying vacuum and the sample was stored in the dark for 5 days at 25°C for complete mineralization of microbial biomass nutrients (Anderson and Ingram, 1993). After 5 days, the soil was extracted with same K_2SO_4 solution and the extract was analyzed for dissolved organic carbon (Ct_1). Microbial biomass carbon was calculated by the formula ($\text{Ct}_1 - \text{Ct}_0$) \times 2.64 (Vance et al., 1987). For microbial biomass nitrogen analysis, the fumigated and non-fumigated samples were digested (Anderson and

Ingram, 1993). From the digested samples, nitrogen was analyzed by modified Kjeldahl method. Microbial biomass nitrogen was calculated by the formula $(Nt_1 - Nt_0) \times 1.46$ (Brookes et al., 1985). NaHCO_3 was used for phosphorus extraction in both fumigated and non-fumigated samples. The extracted P was determined by chlorostannous-reduced molybdophosphoric blue color method (Jackson, 1967). The correction for chloroform released P that was absorbed by soil during extraction was made by adding a known quantity of P during extraction and then correcting for its recovery. Microbial biomass P was calculated by the formula: $(Pt_1 - Pt_0) \times 2.5$ (Brookes et al., 1982).

All statistical analyses were performed using SYSTAT version 6.0, SPSS Inc. (1996). Statistical analysis between land-use, seasons and their interactions was based on analysis of variance (ANOVA). Statistical differences among the land-use were determined using Tukey's honestly significant difference test ($P < 0.05$). Simple regression analyses were employed to compare the strength of relationships between different parameters as a function of land-use.

Results

Soil characteristics

Most soils in the watershed are acidic (pH ranged from 5.02 to 6.43; Table 1). Average soil moisture levels ranged from 17% in wasteland sub-tropical to 34% temperate natural forest dense. In order to assess the effect of change in land-use on soil fertility, the nutrient levels of soils from different land-use were estimated (Table 1). As expected, all nutrients were higher in temperate natural forest dense and lower in sub-tropical wasteland.

Microbial C, N, and P

Across the land-use, mean annual microbial C ranged from 219 to $864 \mu\text{g g}^{-1}$, microbial N from 30 to $142 \mu\text{g g}^{-1}$, and microbial P from 12 to $43 \mu\text{g g}^{-1}$ soil, increasing to a peak in temperate natural forest and declining to a minimum in the wasteland subtropical (Table 2). Analysis of variance for microbial biomass C ($F_{8,135} = 80.28$, $P < 0.0001$), microbial biomass N ($F_{8,135} = 134.22$, $P < 0.0001$) and microbial biomass P ($F_{8,135} = 83.81$, $P < 0.0001$) showed significant variation with land-use. Microbial biomass C, N and P were significantly greater in the canopy closed temperate natural forest than other land-uses ($P < 0.05$), whereas

mean difference between open cropped and wasteland areas of both the belts were not significantly different ($P > 0.05$) (Table 2).

The seasonal pattern of soil microbial C, N and P were similar in all land-use, the values being highest in the dry winter and lowest in the rainy season. Microbial biomass was consistently significantly higher at dense temperate natural forest than other land-uses, regardless of season (Table 3). Analysis of variance indicated significant differences ($F_{2,135} = 85.90$, $P < 0.0001$; $F_{2,135} = 190.71$, $P < 0.0001$ and $F_{2,135} = 39.31$, $P < 0.0001$) in the levels of microbial C, N and P due to season. Interaction between the land-use and season was not significant in microbial biomass C ($F_{16,135} = 1.06$) but significant in microbial biomass N ($F_{16,135} = 8.51$, $P < 0.0001$) and microbial biomass P ($F_{16,135} = 3.55$, $P < 0.0001$). Mean difference within season was significant between winter and spring, rainy and spring and rainy and winter ($P < 0.05$).

Biomass C, biomass P, biomass C and biomass N were significantly correlated ($r = 0.934$ and $r = 0.869$, respectively, $P < 0.0005$). Additionally, biomass C and organic C, biomass N and total N, and biomass P and total P were positively correlated (Fig. 2).

The land transformation from forest to other usage led to changes in soil properties. Soil nutrients and microbial C, N and P declined uniformly due to land transformation (Table 4). The loss in the organic C, total N and total P on land-use basis were 64%, 48% and 44%, respectively, in sub-tropical wasteland. Similarly, the decline in microbial C, N and P were 75%, 79% and 72%, respectively. The rainfed sub-tropical open crop field lost about 59% organic C, 28% total N and 15% total P. The reductions in microbial C, N and P due to cultivation were 66%, 76% and 63%, respectively. This indicates that the loss in microbial nutrients is higher than that in soil nutrients.

Discussion

The conversion of forest into other land-uses resulted in a decrease in plant biomass (Srivastava and Singh, 1991). Land transformation also caused reductions in organic C and other nutrients and the microbial properties and thus a decrease in microbial biomass in soil may be expected (Cleveland et al., 2003). Probably, the decrease in soil nutrients and in microbial C, N and P due to land-use change reflects the decline in plant biomass (Srivastava and Singh, 1991; Wagai et al., 1998).

Table 2. Microbial C, N and P in soil of different land-use/cover types

Land-use/cover	Microbial C	Microbial N	Microbial P	Microbial C:N	Microbial C:P	Microbial C:N:P	Microbial Organic C (%)	Microbial Total N (%)	Microbial Organic P (%)
	$(\mu\text{g g}^{-1})$								
	$n = 3 \text{ seasons} \times 2 \text{ years} \times 3 \text{ sites}$								
Temperate natural forest dense	864 ± 57 ^e	142 ± 17 ^e	43 ± 4 ^d	6.0	20	20:3:1	2.7	4.9	7.8
Temperate natural forest open	712 ± 53 ^d	96 ± 10 ^d	31 ± 2 ^c	7.4	23	23:3:1	2.7	3.9	6.8
Subtropical natural forest open	764 ± 36 ^e	71 ± 8 ^c	31 ± 2 ^c	10.8	25	25:2:1	5.2	3.0	6.5
Cardamom based agroforestry	583 ± 59 ^c	63 ± 9 ^b	22 ± 1 ^b	9.2	27	27:3:1	2.6	2.7	3.7
Mandarin based agroforestry	471 ± 49 ^b	48 ± 6 ^a	18 ± 1 ^a	9.8	26	26:3:1	3.3	2.5	3.1
Open cropped area temperate	390 ± 39 ^a	38 ± 5 ^a	16 ± 1 ^a	10.3	24	24:2:1	1.8	1.9	2.7
Open cropped area subtropical	291 ± 25 ^a	34 ± 5 ^a	16 ± 1 ^a	8.6	18	18:2:1	2.2	1.7	2.9
Wasteland area temperate	259 ± 33 ^a	33 ± 4 ^a	13 ± 0.7 ^a	7.8	20	20:3:1	1.5	1.7	3.7
Wasteland area subtropical	219 ± 34 ^a	30 ± 4 ^a	12 ± 0.8 ^a	7.3	18	18:3:1	1.9	1.9	3.3

Values numbered with different letters differ significantly ($P < 0.05$) (Tukey's honestly significant difference test).

Table 3. Seasonal variation in microbial biomass C, N and P in different land-use systems of Mamlay watershed in Sikkim

Land-use	Microbial C ($\mu\text{g g}^{-1}$)			Microbial N ($\mu\text{g g}^{-1}$)			Microbial P ($\mu\text{g g}^{-1}$)		
	S	R	W	S	R	W	S	R	W
Temperate natural forest dense	882 \pm 146	671 \pm 119	1039 \pm 112	156 \pm 28	74 \pm 16	194 \pm 25	46 \pm 10	29 \pm 4	54 \pm 8
Temperate natural forest open	724 \pm 122	524 \pm 84	886 \pm 148	94 \pm 14	64 \pm 14	130 \pm 26	31 \pm 5	24 \pm 5	38 \pm 9
Subtropical natural forest open	761 \pm 136	641 \pm 88	889 \pm 186	73 \pm 8	41 \pm 8	100 \pm 13	32 \pm 5	26 \pm 5	36 \pm 6
Cardamom based agroforestry system	576 \pm 72	384 \pm 94	790 \pm 214	61 \pm 11	36 \pm 11	91 \pm 22	21 \pm 3	19 \pm 3	25 \pm 4
Mandarin based agroforestry system	469 \pm 109	313 \pm 103	631 \pm 162	41 \pm 8	31 \pm 3	72 \pm 18	19 \pm 2	16 \pm 5	20 \pm 3
Open cropped area temperate	377 \pm 69	263 \pm 82	529 \pm 137	32 \pm 7	24 \pm 4	57 \pm 11	16 \pm 3	14 \pm 2	19 \pm 7
Open cropped area subtropical	292 \pm 98	222 \pm 27	360 \pm 104	29 \pm 11	22 \pm 6	52 \pm 14	15 \pm 2	15 \pm 7	18 \pm 5
Wasteland area temperate	237 \pm 83	166 \pm 57	374 \pm 76	28 \pm 8	21 \pm 2	50 \pm 10	12 \pm 2	11 \pm 2	15 \pm 2
Wasteland area subtropical	170 \pm 63	131 \pm 31	355 \pm 64	24 \pm 3	20 \pm 5	44 \pm 7	11 \pm 3	10 \pm 2	14 \pm 2

Data are pooled for soil samples collected at three sites in two years ($n = 6$). Values are in mean (± 1 SD). S = Spring; R = Rainy; W = Winter (seasons).

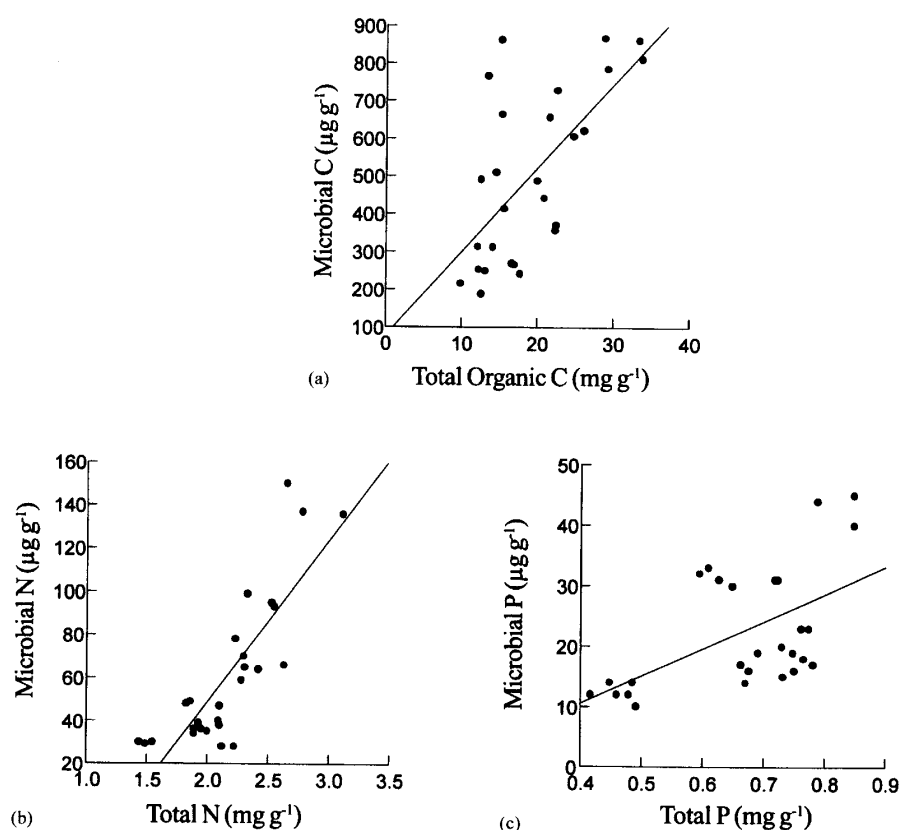


Figure 2. Relationship between (a) microbial biomass C and total organic C ($y = 76.8 + 22.2x$; $r^2 = 0.422$, $P < 0.0005$), (b) microbial biomass N and total N ($y = -101.4 + 75.1x$; $r^2 = 0.683$, $P < 0.0005$) and (c) microbial biomass P and total P ($y = -7.6 + 45.3x$; $r^2 = 0.314$, $P < 0.0005$).

The conversion of forest into open cropped area is mainly due to population growth and fragmentation of upland farm families. This has been a general trend in the entire Hindu-Kush Himalayan region

(Singh et al., 1984; Rai et al., 1994). The conspicuous land-use change from forest to other usage typically leads to soil nutrient loss, though data vary widely. Generally, crop cultivation results

Table 4. Percent decline in soil nutrients and microbial C, N and P in other land-uses compared to canopy-closed temperate natural forest

Land-use/cover	Microbial C	Microbial N	Microbial P	Organic C	Total N	Total P
Open temperate natural forest	-18	-32	-28	-19	-13	-21
Open subtropical natural forest	-12	-50	-28	-54	-16	-21
Cardamom-based agroforestry	-32	-55	-49	-31	-17	-8
Mandarin-based agroforestry	-45	-66	-52	-55	-32	-16
Open cropped area temperate	-55	-73	-63	-31	-30	-9
Open cropped area subtropical	-66	-76	-63	-59	-28	-15
Wasteland area temperate	-70	-77	-70	-46	-30	-44
Wasteland area subtropical	-75	-79	-72	-64	-47	-44

in larger reduction in soil microbial C, N and P than other usage (Detwiler, 1986; Gunapala and Scow, 1998) due to increased soil disturbance and erosion losses. Contrary to this, Wardle (1998) argued that increasing disturbance levels does not destabilize the microbial biomass. In tropical America, conversion from forest to cropland typically reduces soil C by 20–50% (Detwiler, 1986; Mann, 1986; Eswaran et al., 1993).

The soil studied lost a considerable amount of soil organic C, N and P following land transformation. This depletion can be attributed to changes in biological and physical processes in the soil. Hence, the conversion of close canopy forest to agricultural land to wastelands lead to dramatic changes in microbial biomass. The maximum decrease in microbial C, N and P in wastelands was 78% for microbial N, 73% for microbial C and 71% for microbial P. It indicates that N is a limiting factor in the functioning of wastelands. However, the levels of microbial biomass C, N and P in soils are within the range reported for a variety of soils elsewhere (Marumoto, 1984; Brookes et al., 1984; Robertson et al., 1988; Srivastava and Singh, 1988, 1989). In the present study, microbial biomass varied from 1.5% to 5.2% (mean 2.65) of total organic C and total N in biomass N from 1.7% to 4.9% of total organic N (C:N ratio of 6–11; mean 8.57). Dalal and Mayer (1987) reported a biomass C:N ratio of 8.7–13.2 for Australian arable soils. Srivastava and Singh, (1989) reported a similar C:N ratio (10.5–13.8) for certain Indian tropical forest soils.

Microbial biomass P in the studied soils accounted for 2.7–7.8% (mean 4.5) of total organic P with a microbial C:P ratio of 18–27 (mean 22.33). This compares with the range 1.4–4.7% (biomass C:P ratio 10.6–35.9; mean 14.3) reported by Brookes et al. (1984) for 15 UK soils. The C:P ratio ranged from 15 to 63 in soils under pasture in New Zealand and 9 to 23 in tropical soils in India (Sarathchandra et al., 1984; Srivastava and Singh, 1988). Thus, values recorded in the present study are within the

reported range. Ratios of microbial C:N is more usually reported to be about 6.7 (Jenkinson, 1988) and microbial C:P in the range 15–63 (Brookes et al., 1982; Sarathchandra et al., 1984). The present soils are characterized by a mean microbial C:N:P ratio of 22:3:1.

The temporal variability of the soil microbial biomass is an important component of its turnover and thus contributes to patterns of soil nutrient release and mineralization (Wardle, 1998). Seasonality plays an important role in microbial C, N and P turnover (Wagai et al., 1998). Microbial C, N and P were highest in dry winter season and lowest in rainy season which may be attributed to strong demand for these nutrients by the plants, that grows vigorously during this period. Singh et al. (1989) have reported a reciprocal relationship between plant growth rates (which are highest during the wet period) and microbial biomass (which is highest in the dry period). Increase in soil water potential in the rainy season may induce microbial plasmolysis. Reduced microbial biomass and increased microbial turnover in the wet period may result from feeding by expanded microvore populations (Singh et al., 1989; Raghubanshi et al., 1990; Hernandez-Hernandez and Lopez-Hernandez, 2002).

The results suggest that conversion of forest land to other usage detrimentally affects on the microbial biomass and soil organic matter. Soil C may decline immediately following conversion, but soil C reserves may also recover after a relatively short period of time (Cerri et al., 1991; Neill et al., 1997). Destruction of soil organic matter likely results in a decline in productivity (Matson et al., 1997). In the Himalayan watershed, microbial biomass is directly related to plant biomass and is very sensitive to land-use/cover changes as it decreases remarkably after transformation. Therefore, afforestation of agricultural land is advisable. Furthermore, the loss of organic matter and productivity might be counteracted by

strengthening agroforestry systems and crop residue management.

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