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Evaluation of bamboos in eco-restoration of 'jhum' fallows in Arunachal Pradesh: ground vegetation, soil and microbial biomass

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Abstract

With a view to identify potential bamboo species that can help in soil nutrient binding during restoration of abandoned shifting agricultural lands (jhum fallows), we analyzed the ground vegetation, soil and microbial properties under the canopy of three bamboo species viz., *Bambusa nutans*, *Bambusa arundinacea* and *Dendrocalamus hamiltonii* growing in a 9-year old jhum fallow in the ecologically fragile north-eastern hilly region of India. The results were compared with a grassland to evaluate the role of bamboos in soil nutrient dynamics. Species diversity of ground vegetation was highest under *B. nutans* canopy. Soil pH was neutral and the soil organic matter did not vary significantly between different species growing in the jhum fallow and grassland. Available forms of nitrogen and phosphorus in the soil showed variations among species. Soil microbial carbon and phosphorus were greater in grassland (control site), while microbial nitrogen was in *B. nutans* soil. Significant correlations existed amongst microbial carbon, nitrogen and phosphorus. The study indicates that *B. nutans* could help in rehabilitating the jhum fallows with special respect to soil nutrient enrichment. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Bamboo; Ground vegetation; Grassland; Jhum fallow; Soil microbial biomass

1. Introduction

South and south-east Asia constitutes 80% of bamboo growing areas, and in total, 75 genera and 1250 species of bamboos are distributed in the tropical, subtropical and mild temperate regions of the world (Sharma, 1980). India abodes the world's richest bamboo reserves (Mauria and Arora, 1988),

and the annual production of bamboo in India is about 32% of the total world production of 10 million tones. Natural and/or planted bamboo occurring in about 13% of the total forest area in India (Bahadur and Jain, 1983) is an important source of commercial pulp and many utility products including fuel, fodder and small timber. Out of the 18 genera and 128 species of bamboo inhabiting India, Arunachal Pradesh, the north-eastern frontier zone of the Indian sub-continent, alone harbors 16 genera and 63 species. Some of the common species in the state are *Dendrocalamus hamiltonii*, *D. hookerii*, *Bambusa balcoa*, *B. tulda*, *B. pallida*, *B. nutans*, *B. arundinacea*, *Cephalostachyum capitatum* and *Melocanna baccifera*. The state

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produces 119 831 lakhs of bamboo culms every year. Bamboos are utilized for different livelihood purposes and forms an integral part of human life in the hilly terrains of the state. Abundant bamboos growing in degraded lands in the hill slopes (e.g. abandoned shifting agricultural land, locally called 'jhum' cultivation) holds together the loose sandy-loamy soil formed from geologically young rocks of the eastern Himalayan plateau, and helps in slope stability, reducing run-off and soil erosion (Toky and Ramakrishnan, 1982). Haig et al. (1958) reported that huge tracts of grass and bamboo forests have been established as a result of shifting cultivation in Asia. Soderstrom and Calderon (1979) considered bamboos to be one community that rapidly colonizes the disturbed lands in the region, and due to their adaptability and nutrient conservation role (Rao and Ramakrishnan, 1988), they play a special role in succession. While the impact of bamboo growth on the soil may differ at species level, it is expected to increase the microbial biomass, particularly, in the rhizosphere zone by providing a larger root surface area that would help in enriching soil fertility by acting as a 'sink' and 'source' of the available plant nutrients (Singh et al., 1989).

The role of microbial biomass in soil fertility management was evaluated in various terrestrial ecosystems and was found to play crucial role in N and P dynamics in tropical soils (Hernot and Robertson, 1994; Arunachalam et al., 1999). However, its role in bamboo forests has not received the attention of ecologists, foresters and soil scientists. Nevertheless, data on microbial biomass as influenced by bamboo growth could prove to be a potential index in soil nutrient restoration during the recovery of degraded ecosystems. It is reported that bamboo is one of the major secondary successional species following abandonment of jhum fields, sometimes resulting in 'arrested' succession in north-eastern India (Rao and Ramakrishnan, 1988). Therefore, for the present study, three commonly available species of bamboo viz., *B. nutans*, *B. arundinacea* and *D. hamiltonii* growing in a 9-year old jhum fallow were selected to evaluate their influence on the physico-chemical and biological properties of soil and to determine the contribution of microbial biomass to soil nutrient pool. The study is a part of a major research project that aims to identify potential bamboo species for rehabilitating

the abandoned sloping of agricultural lands ('jhum' fallows) of north-east India, in general, Arunachal Pradesh in particular.

2. Materials and methods

2.1. Study area

The study sites are located in the humid tropical forest belt dominated by tree species like *Mesua ferrea*, *Chukrasia tabularis*, *Terminalia myriocarpa*, *Anthocephalus cadamba*, etc. The understory has dense growth of ferns, and other species like *Lantana camara*, *Eupatorium* spp., *Musa sapientum*, *Oxalis* spp., *Symplocos* spp., etc. Almost all the original vegetation has been cleared in the study area due to various anthropogenic stress events and also to a certain extent by frequent landslides and floods during monsoon. The main anthropological stress was shifting cultivation on the hill slopes and illegal felling. Following clearings, weeds and bamboos invade the degraded sites rapidly. Our study sites were: (1) jhum fallow (1.27 ha) and (2) a grassland (0.9 ha) which were in close proximity to each other, located at 132 m above the sea level with 6–13% slope facing north-east in the Itanagar capital complex of Arunachal Pradesh (latitude 26°28'–29°30'N, longitude 91°31'–97°30'E), north-east India. The bamboo plants were growing in the abandoned jhum field, cultivated 9 years earlier.

The parent rock of the study area is of sub-Himalayan type consisting Neogene molassic sediments (siwaliks) and the soils were sandy loam. The study area experiences three distinct seasons namely, a warm and dry summer (March–May), monsoon (May–September) and a cool and dry winter (October–February). The average annual rainfall is 2500 mm approximately. The average minimum and maximum air temperatures during the study period were 22 and 29°C, respectively; the relative humidity varied from 54 to 75%. The light intensity varied from 690 to 26 200 lux and soil temperature (0–15 cm depth) ranged 19–25°C during the study period.

2.2. Sampling procedures

Three individuals of three different bamboo species in the jhum fallow and a control site, a grassland

Table 1
Characteristics of bamboo species^a

Species	Height (m)	No. of culms per plant	No. of good culms	No. of damaged culms	Average diameter of a culm (cm)	Basal area of total culms (cm ²)	Total volume (m ³)
<i>B. nutans</i>	19.6–20.6	150 ± 15	144 ± 7	6 ± 1	7.263 ± 1.02	43.19 ± 1.32	118967 ± 234
<i>B. arundinacea</i>	8.6–15.6	32 ± 7	23 ± 2	9 ± 2	5.827 ± 0.98	31.49 ± 1.11	7062 ± 92
<i>D. hamiltonii</i>	20.6–21.2	83 ± 11	79 ± 4	4 ± 1	10.531 ± 1.32	90.47 ± 2.37	143879 ± 147

^a ±S.E. ($n = 9$).

were selected for detailed study (vegetation and soil) during October 1999. Understorey vegetation and soil samplings in the case of bamboos were restricted to 2 m distance away from the outermost culm of the respective species, and well within the plant canopy. Plant height (using Ravi altimeter), diameter of culms at breast height of 1.2 m (DBH, using measuring tape), and number of culms per plant were measured for the selected bamboo species. The height of the plant averaged 20.1, 11.5 and 20.9 m for *B. nutans*, *B. arundinacea* and *D. hamiltonii*, respectively. The total number of culms per plant was greatest in *B. nutans*, while it was less by five times in *B. arundinacea* (Table 1). However, the average diameter of the single culm was highest for *D. hamiltonii*. Basal area was also greater in these species. The distance between two consecutive nodes was greatest in *B. nutans*, followed by *B. arundinacea* and *D. hamiltonii*.

Three 1 × 1 m² quadrats were laid for ground vegetation analysis under the canopy of each of bamboo species and nine 1 × 1 m² quadrats were laid in the grassland, and all plants within those quadrats were counted. Basal diameter of each herbaceous plant was measured to calculate basal area. Relative density, relative dominance and relative frequency were calculated species-wise and the summation of the three values gave importance value index (IVI) (Misra, 1968). Nomenclature of plant species followed Hooker (1872–1879). Density, frequency, basal area, IVI were determined following standard methods given in Misra (1968). Community indices such as species richness index, species diversity index, species evenness index and similarity index were computed as follows:

- Species richness index = $(S - 1) / \log_e N$; where S is the number of species and N the total number of individuals (Magurran, 1988).

- Shannon and Wiener's (1963) species diversity index = $-\sum(\eta_i/N) \log_e(\eta_i/N)$; where η_i is the importance value for each species and N the total importance value.
- Pielou's (1966) evenness index = $-\sum(\eta_i/N) \log_e(\eta_i/N) / \log_e S$; where η_i is the importance value for each species, N the total importance value and S the total number of species.
- Sorensen's (1948) similarity index = $[2C / (A + B)] \times 100$; where A is the number of species in stand A, B the number of species in stand B and C the number of species common in stand A and B.

In all the three quadrats of a individual bamboo plant used for ground vegetation analysis, microclimatic variables such as relative humidity and air temperature (using thermo-hygrometer), light intensity (using lux meter) and soil temperature (using soil thermometer) on the floor within the canopy of bamboo species and in grassland, and all plants were measured during peak daylight conditions. Below the canopy of each individual bamboo plant, three soil samples down to a depth of 15 cm were also collected from those quadrats using a soil corer (5.5 cm inner diameter) resulting in nine samples, each in the case of bamboo species, and 15 soil cores were randomly collected in grassland and mixed thoroughly species-wise and/or site-wise. The composite soil sample of each of the bamboo species and grassland was divided equally into two parts; one part was immediately (within 24 h) sieved (2 mm mesh screen) and analyzed for pH (digital pH meter), moisture content (gravimetric method), ammonium-N (indophenol blue method) and nitrate-N (phenol disulfonic acid method) and available P (molybdenum blue method). The other part of the soil was sieved through 2 mm mesh screen, air dried

under laboratory conditions for 7 days, and were determined for texture (boyoucou hydrometric method), water holding capacity (Keen's box method). The remaining air dried soil samples were again sieved through 0.5 mm mesh screen and used for analysis of soil organic carbon (rapid titration method) and total Kjeldahl nitrogen (semi-micro Kjeldahl procedure). All procedures followed are as outlined in Allen et al. (1974) and Anderson and Ingram (1993).

For the estimation of microbial population and biomass, another set of three soil samples (0–15 cm depth) were collected down. In this case, the corer was wiped with absolute ethanol before every insertion to prevent any external microbial contamination. Soils were used within 24 h of sampling for the determination of all microbial properties. We considered 10 replications for all analytical determinations. The bacterial and fungal populations were determined using dilution plate techniques on nutrient agar and rose bengal agar medium, respectively. Soil bacterial population was estimated by Waksman's (1952) method using the nutrient agar medium at 10^5 dilution. Fungal population was estimated by dilution plate method (Johnson and Curl, 1972) using Martin rose bengal agar medium at 10^3 dilution in water. The inoculated petri-dishes were incubated at $30 \pm 1^\circ\text{C}$ for 24 h and $25 \pm 1^\circ\text{C}$ for 5 days for bacteria and fungi, respectively.

Microbial N and microbial C were estimated by chloroform fumigation extraction method (Anderson and Ingram, 1993) using two sets of treatment (chloroform fumigated and unfumigated) and extracted in 0.5 N K_2SO_4 and simultaneously digested and titrated against ferrous ammonium sulfate using 1,10 phenanthroline monohydrate as the indicator and N/140 HCl using boric acid indicator, respectively. While, microbial P was estimated by chloroform fumigation extraction technique (Anderson and Ingram, 1993) using 0.5 N NaHCO_3 (Brookes et al., 1984). In all cases, the values of unfumigated samples were subtracted from fumigated one to get the values for microbial C, N and P. Soil respiration was measured by incubating 500 g soil samples with 25 ml NaOH and 25 ml water for 24 h in a sealed, rectangular 1-l jar. After incubation the alkali was titrated against 1 N HCl using phenolphthalein indicator (MacFadyen, 1970).

2.3. Statistical analysis

LSD at 95% confidence level and Tukey's test was used to compare the mean values across the sites. Linear regression were worked out whenever necessary following Zar (1974).

3. Results

3.1. Ground vegetation characteristics

There were 10 herbaceous species under the canopy of *B. nutans* of which a Malvaceae member *Urena lobata* was the dominant species having an importance value of 54.4 (Table 2); *Arundinella mutica* was the only monocot. Under the canopy of *B. arundinacea*, five species were identified of which one was a pteridophyte (*Gleichenia linearis*) which constituted 33.2% of the IVI. This species was followed by a Cucurbitaceae member *Solena heterophylla* having an importance value of 78. *Ageratum conyzoides* was the dominant species under the canopy of *D. hamiltonii* followed by *Ludwigia* spp. and *Crotalaria cytisoides*. In the grassland, *Cynodon dactylon* was the dominant species (IVI = 116.1) followed by *A. mutica* that occupied 31.2% of the total dominance (IVI = 93.7).

The total density of ground vegetation was 57, 42, 43 and 304 m^{-2} in *B. nutans*, *B. arundinacea*, *D. hamiltonii* and grassland, respectively. Basal area of the constituent species was greater under the canopy of *B. nutans*, where the total number of species was also highest (10). The species diversity index was lowest in grassland (1.29) while it was highest in the *B. nutans* (2.2). Eventually, the species richness index was greater in this site (Table 3). The species evenness index show less variation between sites, although the species were regularly distributed under the canopy of *B. nutans*.

3.2. Microclimate and soil properties

The air temperature was highest in grassland and lowest under the canopy of *B. nutans*. Similar trends were shown by light intensity and soil temperature. Light intensity was least under *B. arundinacea*. Relative humidity was greater under the canopy of

Table 2
Species composition, density and IVI of ground vegetation below bamboo canopy and in grassland

Species	Density (plants per m ²)	Frequency (%)	Basal area (cm ² m ⁻²)	IVI ^a
<i>B. nutans</i>				
<i>Desmodium motorium</i>	2	60	0.0314	13.8
<i>Grewia hirsuta</i>	8	100	0.0706	33.0
<i>Psidium guajava</i>	2	60	0.0314	13.8
<i>Phegopteris aurita</i>	12	100	0.0706	40.1
<i>Urena lobata</i>	17	100	0.1256	54.4
<i>Vitis</i> spp.	2	60	0.1963	30.5
<i>Phyllanthus glaucus</i>	2	60	0.1256	23.4
<i>Erigeron bonariensis</i>	3	100	0.0706	24.3
<i>Macaranga indica</i>	5	100	0.0706	27.8
<i>Arundinella mutica</i>	4	100	0.1963	38.8
<i>B. arundinacea</i>				
<i>Albizia lucida</i>	3	80	0.0706	38.8
<i>Desmodium motorium</i>	5	80	0.0314	35.6
<i>Eragrostis nigra</i>	5	100	0.0706	47.9
<i>Gleichenia linearis</i>	16	100	0.1963	99.5
<i>Solena heterophylla</i>	13	100	0.1256	78.1
<i>D. hamiltonii</i>				
<i>Ageratum conyzoides</i>	11	100	0.1256	80.2
<i>Crotalaria cytisoides</i>	7	100	0.0706	55.5
<i>Ludwigiaspp.</i>	13	100	0.0282	57.8
<i>Mesua ferrea</i> ^b	1	40	0.0314	17.4
<i>Mikania micrantha</i>	3	80	0.0706	55.5
<i>Spilanthes paniculata</i>	8	100	0.0314	46.9
Grassland				
<i>Cynodon dactylon</i>	149	100	0.1256	116.1
<i>Eleusine indica</i>	8	100	0.0706	51.3
<i>Spilanthes paniculata</i>	10	100	0.0314	38.8
<i>Arundinella mutica</i>	137	100	0.0706	93.7

^a Importance value index.

^b Seedlings.

bamboos than in the grassland (Table 4). Bulk density of soils ranged 1.21–1.56 g cm⁻³. The porosity was higher (16.42%) in *B. arundinacea* and lowest in grassland. Soil moisture content was greater under

D. hamiltonii and lowest under *B. arundinacea* (Table 5). In general, the pH was near neutral (6.7–7.0), the soil organic matter also did not vary significantly between the three different bamboo

Table 3
Species richness and diversity of herbaceous vegetation under the canopy different bamboo species and in grassland^a

Plant name/site	Density (plants per m ²)	Basal area (cm ² m ⁻²)	Species number	Evenness index	Richness index	Diversity index
<i>B. nutans</i>	57 ± 11	0.989 ± 0.12	10	0.965	2.226	2.223
<i>B. arundinacea</i>	42 ± 5.6	0.295 ± 0.17	6	0.953	1.334	1.711
<i>D. hamiltonii</i>	43 ± 3.7	0.494 ± 0.12	5	0.947	1.337	1.526
Grassland	304 ± 27	0.298 ± 0.09	4	0.935	0.525	1.296

^a ± S.E. (n = 9).

Table 4
Microclimatic variability in the study sites^a

Site	Air temperature (°C)	Relative humidity (%)	Light intensity (lx)	Soil temperature (°C)
<i>B. nutans</i>	25 ± 1	57 ± 1	1680 ± 112	22 ± 2
<i>B. arundinacea</i>	26 ± 2	54 ± 6	690 ± 97	19 ± 3
<i>D. hamiltonii</i>	25 ± 1	55 ± 2	2620 ± 128	20 ± 2
Grassland	28 ± 2	47 ± 2	2800 ± 240	24 ± 1
LSD at 0.05 level	1.2	3.7	841.4	1.9

^a ±S.E. ($n = 9$).

Table 5
Soil physical properties in the study sites ($n = 9$)

Site	Bulk density (g cm ⁻³)	Porosity (%)	WHC (%) ^a	SMC (%) ^b
<i>B. nutans</i>	1.215	6.415	34.48	18.965
<i>B. arundinacea</i>	1.385	19.62	43.15	17.125
<i>D. hamiltonii</i>	1.355	13.96	39.01	22.330
Grassland	1.560	13.39	44.12	18.200
LSD at 0.05 level	0.12	2.5	3.8	1.9

^a Water holding capacity.

^b Soil moisture content.

species and grassland. The total Kjeldhal nitrogen, however, showed distinct variations between sites. The nitrogen level was greater in the grassland and lower in the soils of *B. nutans*. Similarly, available P level in the soil was highest (301.25 µg g⁻¹) in the *B. arundinacea* plot, while the minimum value was recorded in *B. nutans*. The nitrate concentration was lower than the ammonium concentration in *B. nutans* and *B. arundinacea*, whereas it was greater in the other two cases. The site-wise trends in ammonium and nitrate concentrations were: ammonium — *B. arundinacea* > *B. nutans* > Grassland > *D. hamiltonii*; nitrate — Grassland > *D. hamiltonii* > *B. arundinacea* > *B. nutans* (Table 6).

Table 6
Soil chemical properties in the study sites ($n = 9$)

Site	pH	SOC (%) ^a	TKN (%) ^b	Available P (µg g ⁻¹)	Ammonium (µg g ⁻¹)	Nitrate (µg g ⁻¹)	C/N
<i>B. nutans</i>	6.96	4.214	0.126	92.25	4.225	2.765	33.4
<i>B. arundinacea</i>	7.035	4.106	0.210	301.25	4.930	3.350	19.5
<i>D. hamiltonii</i>	6.70	4.149	0.406	110.00	2.135	3.840	10.2
Grassland	6.90	4.471	0.504	102.00	2.290	9.180	8.8
LSD at 0.05 level	0.12	0.14	0.14	8.66	1.21	2.57	

^a Soil organic carbon.

^b Total Kjeldhal nitrogen.

3.3. Microbial properties

The soil biological properties were determined in terms of microbial population (bacteria and fungi) and microbial nutrients (C, N, P). The bacterial population in soil was greater in *B. arundinacea*, while *D. hamiltonii* harbored the least microbial population. On the contrary, fungal population was greater in grassland (Table 7). The soil microbial C and microbial P were much greater in the grassland (1476.77 µg g⁻¹), while microbial N was greater in the soils under *B. nutans*.

The contribution of microbial C to soil organic carbon (SOC) was significantly ($P < 0.05$) greater in

Table 7
Soil microbiological properties in the study sites ($n = 9$)

Site	Population		Biomass ($\mu\text{g g}^{-1}$)		
	Bacteria (No. of colonies $\times 10^5 \text{ g}^{-1}$ dry soil)	Fungi (No. of colonies $\times 10^3 \text{ g}^{-1}$ dry soil)	C	N	P
<i>B. nutans</i>	7.404	40.107	434.568	204.00	8
<i>B. arundinacea</i>	10.859	91.705	338.160	120.91	9
<i>D. hamiltonii</i>	7.080	22.531	113.400	133.98	5
Grassland	8.557	96.577	1476.770	142.72	8
LSD at 0.05 level	1.48	32.07	481.49	31.90	1.5

Table 8
Microbial C/N and N/P ratios and contribution of MBC, MBN and MBP to total soil organic carbon (SOC), total Kjeldhal nitrogen (TKN) and available P ($n = 9$)

Site	MBC ^a to SOC (%)	MBN ^b to TKN (%)	MBP ^c to available P (%)	Microbial	
				C/N	N/P
<i>B. nutans</i>	3.5	16.19	86.7	2.13	25.5
<i>B. arundinacea</i>	0.82	5.76	29.9	2.79	13.4
<i>D. hamiltonii</i>	0.80	3.30	45.5	2.48	22.3
Grassland	3.30	2.83	78.4	10.35	17.8

^a Microbial biomass carbon.

^b Microbial biomass nitrogen.

^c Microbial biomass phosphorus.

the grassland as well as under *B. nutans*. Similar trend was observed for the contribution of microbial N and microbial P to the total Kjeldahl nitrogen and available P in the soil (Table 8). The least contribution in terms of nitrogen and carbon was recorded in *D. hamiltonii*. While the least contribution (2.99%) in terms of phosphorus was observed for *B. arundinacea*.

4. Discussion

Although, the three bamboo species were growing contiguously in the same site, we observed spatial differences in the distribution of herbaceous vegetation, soil nutrients, and microbial population and biomass. The root causes of this spatial heterogeneity is not presently understood. Nevertheless, in a situation where rainfall is high (over 2000 mm annually) and monsoonic, and the soil is sandy, loamy and porous this spatial heterogeneity may have potential to nutrient retention, especially when the system is ecologically fragile and nutrient poor (Pandey and Singh, 1985). In the grassland, only

light demanding and shade intolerant species like *C. dactylon* and *A. mutica* showed greater importance value of 116 and 94, respectively. While, beneath the canopy of bamboo species, shade loving dicot plants were abundant (Table 2).

Soil pH remained neutral in all sites with similar SOC content as the bamboo plants were in the site and the soils have developed from a single parent rock. However, total Kjeldahl nitrogen (TKN) was significantly higher ($P < 0.05$) in grassland. Among the bamboo soils, TKN was greater under the canopy of *D. hamiltonii*, while it was reduced by 50% in *B. arundinacea* and again half-reduced in *B. nutans*. It appears that the growth of bamboo exerts a greater impact on the N and P turnover than the C turnover in the soil. This is confirmed by greater concentration of available forms of nitrogen in the grassland. The ratio of available N (ammonium + nitrate) to available P signifies low N mineralization rates beneath bamboo canopy. This could be due to the type and quality of plant residues and also the composition of decomposer population (Maithani et al., 1998). Microbial C ($333\text{--}1477 \mu\text{g g}^{-1}$) values were well within those reported

by Vance et al. (1987) for various terrestrial ecosystems ($61\text{--}1900 \mu\text{g g}^{-1}$). The microbial C and N in grassland (control) was comparable to that of a 'sacred grove' at upper Shillong (1532 and $156 \mu\text{g g}^{-1}$; Arunachalam et al., 1994). There was a significant positive correlation between SOC and microbial C ($r = 0.726$, d.f. = 39, $P < 0.001$). The dynamics of N in the mineral soil is closely linked to C, because most N exists in organic compounds and heterotrophic microbes, which utilize organic-C for energy. As a result, microbial N showed a positive correlation with microbial C ($r = 0.831$, d.f. = 39, $P < 0.001$). Joergensen et al. (1995) reported that above the soil pH 5.0, microbial C/N ratios vary within a narrow range. Our study does not corroborate this as there were vast differences in microbial C/N ratio between sites, though soil pH did not vary significantly. They also suggested that soils with comparatively low C and N availability may result in microbial C/N ratios which are well below the optimum values, i.e. 5–8. In this study, the soils under bamboo canopies had microbial C/microbial N ratios below 5 and in grassland the ratio exceeded 8. This again indicates low availability of N in the soils studied (Tripathi and Singh, 1994). However, soil specific differences in population structure and associated functioning of microbial population are also important in regulating the C/N ratio in microbial biomass. Nonetheless, the microbial biomass in the bamboo soils was dormant, because of very small microbial C/N ratio (2.13–2.79) (Bremner and van Kessel, 1992). The microbial P values in this study ($5\text{--}9 \mu\text{g g}^{-1}$) were very low as compared to the values reported by Brookes et al. (1984) for grasslands and woodlands ($12\text{--}67 \mu\text{g g}^{-1}$) and Arunachalam et al. (1996) for *Pinus kesiya* forest ($4.9\text{--}19.6 \mu\text{g g}^{-1}$). However, the values were in the lower order of the range reported for arable lands ($5\text{--}28 \mu\text{g g}^{-1}$) by Brookes et al. (1984). There was a positive correlation between microbial C and microbial P ($r = 0.602$, d.f. = 39, $P < 0.001$). This fully corroborates the findings of the above authors. The relationship between microbial N and microbial P was also significant ($r = 0.543$, d.f. = 39, $P < 0.01$).

The contribution of microbial biomass to soil nutrient pool was in the following order:

- *Microbial C to SOC: B. nutans* > Grassland > *B. arundinacea* > *D. hamiltonii*.
- *Microbial N to TKN: B. nutans* > *B. arundinacea* > *D. hamiltonii* > Grassland.
- *Microbial to available P: B. nutans* > Grassland > *D. hamiltonii* > *B. arundinacea*.

These trends indicate that the contribution of microbial biomass to the soil nutrient pool (C, N and P) was greatest in the soils of *B. nutans* that would help conservation of these elements vis-à-vis support the growth of several herbaceous plants under its canopy and also the bamboo itself by acting as a 'sink' and 'source' of available plant nutrients. Thus, *B. nutans* with its fairly good morphological characteristics as compared to other bamboo species studied could prove to be a potential species for rehabilitating the ecologically degraded slopes in general and jhum fallows in particular. Nevertheless, further extensive studies are required to arrive at any holistic conclusion.

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