J. Bamboo and Rattan, Vol. 3, No. 2, pp. 169–183 (2004)

Also available online - www.vsppub.com

Effect of bamboo foliage on soil respiration, microbial biomass and N mineralization

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Abstract—Microbial N, CO_2 evolution rate and mineral-N dynamics were determined in soils collected beneath the canopy of two different bamboo species in a 9-year-old bamboo forest developed on an abandoned sloping agricultural land in a humid tropical zone of north-east India. A laboratory incubation study was set up to determine the dynamics of microbial biomass, soil respiration and N mineralization rates as influenced by addition of bamboo residues (leaves and scale leaves). Soil nutrients and microbial biomass C, N and P were greater in soils under *Bambusa pallida* as compared to *B. balcooa.* Lignin and N concentrations were greater in *B. balcooa.* Scale leaves had low lignin and N concentrations than the leaf litter. The litter quality, particularly lignin/N, influenced the dynamics of soil mineral-N and, therefore, on the net N mineralization rate. CO_2 evolution rate in the soil had a negative relationship with the N mineralization rate, while the microbial N showed weaker correlations with the dynamics of the mineral N. Overall, amendments using the sclerophyllous and slow decomposing foliage did not contribute to the increasing N mineralization in the soils. The study also suggests that soil management practices in bamboo forests should take into account incorporation of residues of good quality, probably of other plant species, failing which, soil quality may deteriorate over a long term that would be critical in productivity and nutrient cycling of secondary bamboo forests regenerating on nutrient-poor, fragile and marginal fallow agricultural lands.

Key words: Bamboo; foliage; microbial biomass; N mineralization; soil respiration; Northeast India.

INTRODUCTION

Leaf litter is one of the major sources of soil organic matter in an ecosystem and it is an energy source for heterotrophic organisms and a nutrient reservoir for intra-system cycling of important soil nutrients. The nutrients trapped in leaf litter are mineralised through the microbe-fauna-mediated decomposition subsystem which is affected by physical and chemical characteristics of the soil [1], as well as the substrate quality as it determines the rate of litter decay and subsequent nutrient

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release [2]. Concentrations of C, N, P, cellulose, hemicellulose, polyphenols, lignin, C/N and lignin/N ratios, etc., are some of the important chemical indices of substrate quality that govern nutrient mineralization and/or accumulation processes in the litter. These characteristics of litter are also expected to influence the indicator of soil metabolism i.e. soil respiration. It is considered to be related to the decomposition of organic matter and nutrient turnover in soils [3]. While most studies on N mineralization and litter decomposition have concentrated on the broadleaved tree species [2, 4, 5], limited efforts have been made to study and understand the role of bamboo foliage and roots on soil nutrient cycling.

In the humid tropics of Northeast India, bamboos are considered to be the primary colonizers in abandoned jhum (slash-and-burn agriculture) fallows [6]. It helps in ecosystem recovery of degraded soils and at times results in arrested succession in degraded sites [7]. Bamboo leaves and scale leaves form the major organic inputs to the soil in such bamboo forests, the quality of which may highly influence the nutrient dynamics in those soils. Recently, we reported that soils under two different bamboo species differ in their physico-chemical properties [8]. *Bambusa balcooa* and *B. pallida* are common in north eastern India, particularly in Assam and Arunachal Pradesh [9]. *Bambusa pallida* possess smaller leaves and scale leaves and produces smaller culms (5–7 cm diameter) as compared to *B. balcooa* (5–10 cm diameter) and grows luxuriantly in the degraded hill slopes affected by shifting agriculture in Arunachal Pradesh. The difference in leaf size is expected to have variations in chemical composition that would govern the decay pattern and nutrient mineralization. Further foliage decomposition will have a bearing on the nutrient dynamics of the degraded and/or regenerating vegetation. Therefore, we determined litter chemistry of these two humid tropical bamboo species, *viz.*, *B. balcooa* Roxb. and *B. pallida* Munro., and analysed their effects on N-mineralization and soil respiration.

MATERIALS AND METHODS

Soil and litter sampling

The study plants were two bamboo species, *viz.*, *B. balcooa* and *B. pallida*, growing in a bamboo forest (9 year old; 126 m asl) developed on a fallow agricultural land due to long-term abandonment after shifting cultivation in the humid tropics of Arunachal Pradesh (26°28′ and 29°30′ N latitude, and 91°30′ and 97°30′ longitude), India. The average annual rainfall of the place was about 1800 mm with mean maximum and minimum air temperatures of 33°C and 18°C, respectively. The soil in the study area has developed from geologically young rocks of the Siwalik formations of the sub-Himalayan type consisting of Neogene molassic sediments.

Top soil (0–10 cm) under the canopy of *B. balcooa* and *B. pallida* was collected in bulk during March 1999. The soils were sieved through a 2-mm mesh and the initial pH, moisture content (gravimetric method), and concentration of ammonium-N (indophenol blue method) and nitrate-N (phenol disulphonic acid method)

were determined within 24 h after sampling. The remaining soil samples were air-dried and analysed for texture, water holding capacity (WHC), soil organic carbon (SOC), total Kjeldahl nitrogen (TKN) and available-P according to standard procedures [10].

Freshly fallen foliage litter samples of the two bamboo species were also collected during March 1999. The litter was sorted into leaves and scale leaves, air-dried (for one week in laboratory conditions) and chopped into 5-mm sections using sterilized scissors. Sub samples of litter were oven-dried at 105°C for 24 h in order to determine their dry weights. The ash content of litter was determined by igniting CYCLOTEC ground samples in a muffle furnace at 550°C for 6 h. The carbon content was estimated taking 50% of the ash-free weight [11]. TKN was determined using the semi-micro Kjeldahl procedure and total-P was estimated using the molybdenum blue method [10]. The lignin content of the samples was determined according to Peach and Tracey [12].

Laboratory N mineralization, microbial N and soil respiration

Field moist soil (250 g, 2 mm sieved), collected from under each bamboo canopy, was kept in a 500-ml polyethylene beaker and adjusted to 60% WHC. The air-dried and chopped leaf and scale leaf litter samples from each bamboo species were mixed with their respective soil with a loading rate of 0.01 g plant material g^{-1} dry soil. Two vials (50 ml) were kept inside the beaker, one with 20 ml 1 M NaOH and the other one with 20 ml deionised H_2O. The beakers were sealed with polythene sheets and incubated for 90 days at 25 ± 1°C in a BOD incubator. For each bamboo species, the treatments were: soil only (as control), soil plus scale leaf and soil plus leaf. About 24 replicates for each treatment were set up. The moisture content of the incubated soil samples was kept constant throughout the experiment by periodic addition of deionised water. At a given sampling, 6 beakers were randomly chosen from each treatment for further analysis. The pH, moisture content and concentrations of ammonium-N and nitrate-N in soil were measured photometrically [9] at 30, 60 and 90 days. At the same time interval, the microbial N was also measured using modified chloroform-fumigation extraction method [13, 14]. Soil respiration (CO_2 evolution) was estimated through the alkali absorption method using 1 N NaOH placed in the sealed polythene beakers at a 10-day interval [4].

The net N mineralization rate was calculated by subtracting the initial inorganic N (ammonium + nitrate) present in the soil from the N accumulated in the soil during the respective incubation period. The N mineralization rate ($\mu g\, g^{-1}\, day^{-1}$) was (Final concentration − Initial concentration)/Incubation days. By subtracting the total extractable N in the control from that of the litter plus soil treatment, accumulation or depletion of inorganic N attributable to the presence of litter samples was calculated.

Statistics

To determine the statistical significance of variations among the chemical properties of leaf litter when added, including mineral N concentrations, microbial N and soil respiration, Tukey's test was used. Linear regression was done wherever necessary following Zar [15].

RESULTS

Initial chemical composition of leaf/scale leaf litter

The C content was significantly ($P < 0.05$) higher in the foliage of *B. pallida* than in *B. balcooa*. Likewise, in each species, the C concentration was greater in scale leaves than in the leaf litter. An opposite trend was observed for the N and lignin concentrations. P concentration did not vary significantly between leaf litter and scale leaves of *B. balcooa*, whereas the scale leaves of *B. pallida* contained significantly ($P < 0.05$) higher P concentration than the leaf litter. Significant differences in C/N and lignin/N ratios were also noted between leaf and scale leaves samples of each species. These ratios were significantly higher in *B. pallida* leaf and scale leaf samples than in the other species. *B. pallida* scale leaves recorded almost double the C/N ratio of *B. balcooa* and 1/3 increase of the lignin/N ratio (Table 1).

Initial soil physico-chemical properties

Soils under both species were loamy sand (Table 2) and relatively more acidic under *B. balcooa* (pH 5.99) as compared to *B. pallida* (pH 6.52). Water holding capacity (WHC) and clay content were higher in the *B. balcooa* soil. On the other hand, the *B. pallida* soil showed a significantly higher ($P < 0.01$) soil organic matter (SOM), total Kjeldahl nitrogen (TKN) and available-P than the other species. The ammonium-N and nitrate-N content was more or less similar in both the soils (Table 2).

Table 1.
Initial chemical composition of the foliage litter of two bamboo species

Source of litter	Chemical properties (%)					
	C	N	P	Lignin	C/N	Lignin/N
Bambusa balcooa						
Leaf	44.56^{a}	2.28^{a}	0.031^{a}	31^{a}	19.54	13.60
Scale leaves	46.71^{b}	1.36^{b}	0.032^{b}	25^{b}	34.34	18.38
Bambusa pallida						
Leaf	47.82^{a}	1.80^{a}	0.023^{a}	29^{a}	26.57	16.11
Scale leaves	48.92^{b}	0.71^{b}	0.063^{b}	20^{b}	68.90	28.17

Note: Values under each species with different superscripts are significantly different at $P < 0.05$.

Mineral N flux in soil

The field soil had 5.35 and 5.26 $\mu g\, g^{-1}$ of mineral-N (ammonium + nitrate-N) under the canopy of *B. balcooa* and *B. pallida*, respectively. Concentration of mineral-N increased with the incubation time in all *B. balcooa* treatments. In *B. pallida* treatments, mineral-N concentration decreased after 30 days of incubation and again with further incubation (Table 3). The decrease was about two-fold in leaf samples and about 3 times in scale leaf treatments.

In general, on the 90th day, the ammonium-N concentration was slightly higher in control in case of *B. pallida*, whereas it was significantly greater in *B. balcooa* leaf and scale leaf amended soils. On the other hand, nitrate-N concentration was relatively lower in control in case of the former while the leaf amended soils of both the species showed almost similar concentrations of nitrate-N (Table 3).

N mineralization or immobilization in soil

Net N mineralization rate was significantly higher in control as compared to leaf and scale leaf amended soils each in *B. balcooa* and *B. pallida* (Table 3). In all the treatments of *B. pallida*, immobilization was recorded during initial 30 days which continued up to 60 days in case of scale leaves amended soil. The trend in immobilization rate was control (soil only) < leaf amended soil < scale leaf

Table 2.
Properties of soil (0–10 cm) under the canopy of *B. balcooa* and *B. pallida*

Particulars	*B. balcooa*	*B. pallida*
Soil texture (%)		
Clay	9.54[a]	8.47[b]
Silt	10.79[a]	11.92[b]
Sand	79.67[a]	79.61[a]
Textural class	Loamy sand	Loamy sand
Water holding capacity (%)	64.06[a]	51.70[b]
Soil moisture content (%)	9.90[a]	8.60[b]
Bulk density ($g\, cm^{-3}$)	1.51[a]	1.50[a]
Soil pH	5.99[a]	6.52[b]
Soil organic carbon (%)	1.57[a]	1.87[b]
Soil organic matter (%)	2.71[a]	3.22[b]
Total Kjeldahl N (%)	0.38[a]	0.46[b]
SOC/TKN	4.13[a]	4.03[a]
Ammonium N ($\mu g\, g^{-1}$)	0.014[a]	0.016[a]
Nitrate N (mg/100 g)	0.534[a]	0.524[a]
Available P ($\mu g\, g^{-1}$)	8.89[a]	10.69[b]
Microbial biomass ($\mu g\, g^{-1}$)		
C	479.82[a]	1458.80[b]
N	205.54[a]	405.22[b]
P	2.98[a]	4.23[b]

Note: Values having similar superscripts in each row are not significant at $P < 0.05$.

Table 3.
Changes in soil inorganic N ($\mu g\, g^{-1}$ dry soil) during 90 days of incubation (25°C)

Source of litter	30 days of incubation			60 days of incubation			90 days of incubation		
	Treatment								
	Ammon	Nitrate	Total	Ammon	Nitrate	Total	Ammon	Nitrate	Total
B. balcooa									
Control	0.063	11.62	11.683	0.105	23.97	24.075	0.076	36.97	37.046
Leaf	0.053	10.94	10.993	0.229	11.21	11.439	0.081	28.21	28.291
Scale leaves	0.044	5.32	5.364	0.127	6.67	6.797	0.084	34.62	34.704
B. pallida									
Control	0.107	4.91	5.017	0.063	7.65	7.893	0.080	32.92	33.00
Leaf	0.106	2.52	2.626	0.058	16.62	16.678	0.057	28.20	28.257
Scale leaves	0.034	1.88	1.815	0.057	5.09	5.147	0.036	11.88	11.916

Note: Total = ammon + nitrate; ammon = ammonium.

Table 4.
Ammonification, nitrification and net N mineralization rates of soils amended with bamboo foliage litter over 90 days of incubation

Litter source	Treatment		
	Ammonification ($\mu g\, g^{-1}\, day^{-1}$)	Nitrification ($\mu g\, g^{-1}\, day^{-1}$)	N-mineralization ($\mu g\, g^{-1}\, day^{-1}$)
Bambusa balcooa			
Control	6.89×10^{-4}	0.351	0.352
Leaf	7.44×10^{-4}	0.254	0.255
Scale leaves	7.78×10^{-4}	0.325	0.326
Bambusa pallida			
Control	7.11×10^{-4}	0.308	0.308
Leaf	4.56×10^{-4}	0.255	0.256
Scale leaves	2.22×10^{-4}	0.074	0.074

amended soil (Fig. 1). Control soil under *B. pallida* showed higher ammonification rate ($7.11 \times 10^{-4}\ \mu g\, g^{-1}\, day^{-1}$) than the soil beneath *B. balcooa*, while nitrification and net N-mineralization rates were greater in *B. pallida* (Table 4).

Soil respiration

Initially (at 0 days) soil respiration (CO_2 evolution $\mu g\, g^{-1}$ soil; Table 5) was very high, but decreased sharply with the addition of leaf and scale leaf samples of bamboo. Among bamboo species, soil respiration was generally higher in *B. pallida* amended soil. Overall, scale leaves increased soil respiration as compared to leaves. There was a significant ($P < 0.001$) negative correlation between incubation time and soil respiration.

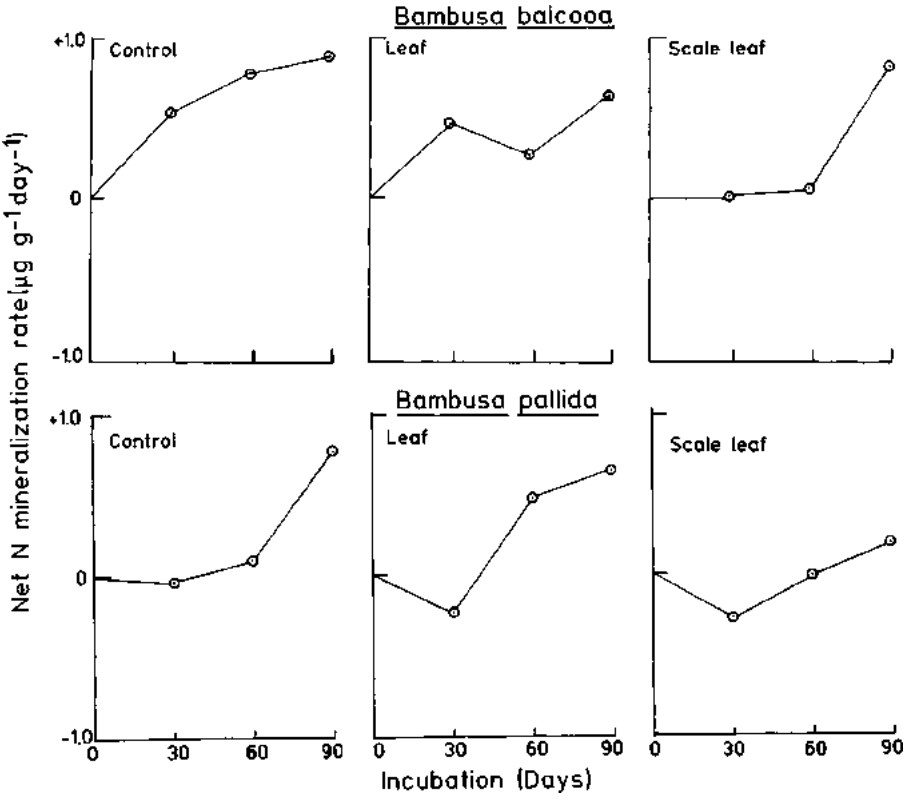

Figure 1. Net N mineralization rate in soil as amended with bamboo foliage.

Table 5.
Soil respiration (CO_2 evolution in $\mu g\, g^{-1}$)

Litter source	Initial	30 days	60 days	90 days
Bambusa balcooa				
Leaf	1772.80[a]	427.12[b]	313.28[c]	123.20[d]
Scale leaves	1772.80[a]	519.20[b]	418.88[c]	176.00[d]
Bambusa pallida				
Leaf	1782.00[a]	644.16[b]	387.20[c]	237.60[d]
Scale leaves	1782.00[a]	797.28[b]	496.32[c]	272.80[d]

Note: Values in each row having different superscripts are significantly different at $P < 0.05$.

Microbial N and N accumulation/depletion in litter

Initially, significantly higher ($P < 0.01$) microbial biomass N (MBN) was recorded in field moist soil under *B. pallida* (405.22 $\mu g\, g^{-1}$) compared to *B. balcooa* (205.54 $\mu g\, g^{-1}$). During incubation, MBN tended to be lower. Nevertheless, the greater microbial-N was recorded on the 90th day of incubation in all the organic amendments, except the leaf amended soils of *B. balcooa,* where the highest value

Table 6.
Microbial N ($\mu g\, g^{-1}$) during 90 days of incubation (25 °C)

Source of litter	Incubation period			
	Initial	30 days	60 days	90 days
Bambusa balcooa				
Control	205.54[a]	197.76[b]	106.17[c]	213.70[d]
Leaf	205.54[a]	217.17[b]	101.37[c]	110.24[c]
Scale leaves	205.54[a]	193.70[b]	192.57[b]	220.00[c]
Bambusa pallida				
Control	405.22[a]	97.96[b]	120.17[c]	166.28[d]
Leaf	405.22[a]	195.87[b]	107.41[c]	215.11[d]
Scale leaves	405.22[a]	96.85[b]	217.15[c]	218.91[c]

Note: Values in each row having different superscripts are significantly different at $P < 0.05$.

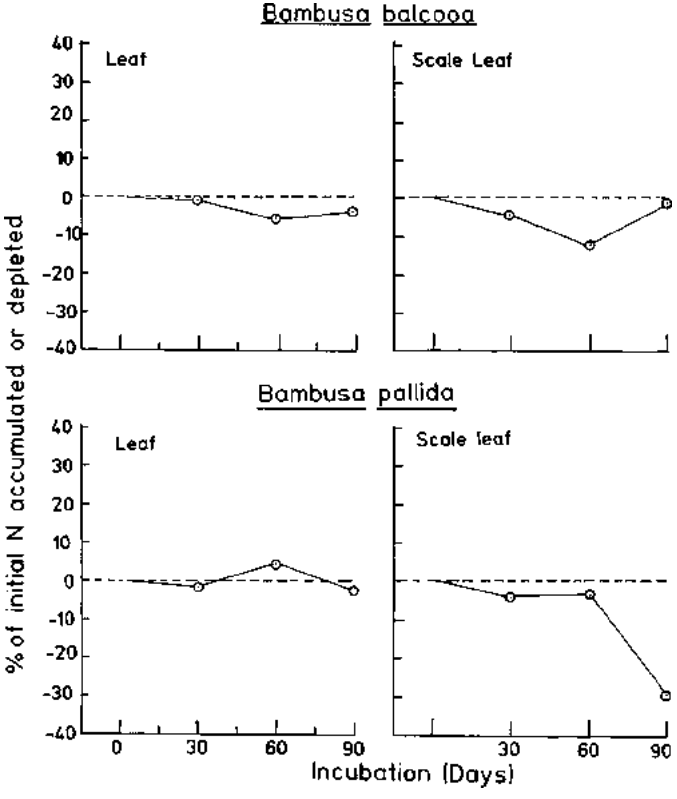

Figure 2. Percentage of initial N accumulated or depleted in bamboo foliage during incubation.

was noted at the end of 30 days of incubation (217.17 $\mu g\, g^{-1}$; Table 6). *B. balcooa* leaf plus soil treatment showed the greater microbial N after 30 days incubation than in scale leaf amended soil (193.70 $\mu g\, g^{-1}$), whereas the latter treatment recorded

the larger value for microbial N than the leaf amended soil on the 60th and 90th day of incubation. A similar trend was observed in case of *B. pallida*. In general, the treatments in both the species showed N accumulation/immobilization in the added foliage throughout 90 days incubation. The highest immobilization was recorded in scale leaf amended soils at the 90th day of incubation in *B. pallida*, whereas mineralization was exhibited only by the leaf amended soil in the same species on the 60th day of incubation (Fig. 2).

Relationships between CO_2 evolution and initial chemical composition of litter and N mineralization

There were positive correlations between CO_2 evolution and initial C, P, C/N and lignin/N and negative correlations between CO_2 evolution and initial N and lignin (Table 7). On the 30th day, the initial N and lignin concentrations had positive correlations with MBN, but after 60 and 90 days of incubation they showed significant negative correlation (Table 7). CO_2 evolution was correlated negatively with ammonification, nitrification and net N-mineralization (Table 7), while microbial N had weaker correlations with N mineralization in the soil.

Relationship between accumulation/depletion and initial foliage chemistry

There was a negative correlation between N accumulated or depleted (%) and initial N and lignin concentrations. Similarly, C/N and lignin/N ratios also exhibited highly significant ($P < 0.001$) positive correlation with litter N accumulation/depletion on the 90th day of incubation (Table 8).

DISCUSSION

Quality of litter

The quality of litter, characterized by initial chemical composition, affects the rate of decomposition thereby influencing turnover rate of organically bound nutrients, especially N. Leaves and scale leaves of both the bamboo species under study showed marked differences in chemical composition, as indicated by the significant variation in C/N ratio (Table 1), which is due mainly to the morphological and anatomical characters of the foliage [2]. Between species, the variation is more in scale leaves than in the leaf litter. The initial N (0.71–2.28%) and lignin (20–31%) concentrations recorded in this study are comparable with the ranges (0.36–3.90% and 4.5–46%, respectively) reported by Vogt *et al.* [3, 16], Van Vuuren *et al.* [17] and Myers *et al.* [18] for various tropical and subtropical tree species. Maithani *et al.* [19] also recorded an almost similar (23–45%) range of lignin concentrations as in this study for various broadleaved tree species of a disturbed subtropical humid forest, but they reported lower concentration of initial N in the litter as compared to the present study. Myers *et al.* [18] reported that organic residues having C/N

Table 7.
Relationships between microbial N and CO_2 evolution with net ammonification, nitrification and N-mineralization rates and initial chemical composition of foliage

Chemical properties	Incubation time (days)		
	30 days	60 days	90 days
CO_2 evolution with:			
Ammonification	-0.072^{ns}	-0.788^{*}	-0.917^{*}
Nitrification	-0.893^{*}	-0.606^{**}	-0.681^{*}
N-mineralization	-0.897^{*}	-0.618^{**}	-0.681^{*}
C	0.960^{*}	0.898^{*}	0.986^{*}
N	-0.827^{*}	0.993^{*}	-0.778^{*}
P	0.701^{*}	0.774^{*}	0.555^{****}
Lignin	-0.784^{*}	-0.971^{*}	-0.711^{*}
C/N	0.861^{*}	0.936^{*}	0.766^{*}
Lignin/N	0.869^{*}	0.948^{*}	0.780^{*}
Microbial N with:			
Ammonification	-0.134^{ns}	-0.296^{ns}	-0.440^{****}
Nitrification	0.590^{***}	-0.685^{*}	-0.093^{ns}
N mineralisation	0.591^{***}	-0.693^{*}	-0.093^{ns}
C	-0.804^{*}	0.609^{**}	0.870^{*}
N	0.912^{*}	-0.936^{*}	-0.758^{*}
P	-0.940^{*}	0.775^{*}	0.255^{ns}
Lignin	0.923^{*}	-0.956^{*}	-0.672^{*}
C/N	-0.991^{*}	0.857^{*}	0.557^{***}
Lignin/N	-0.989^{*}	0.864^{*}	0.586^{***}

$^{*}P < 0.001$.
$^{**}P < 0.005$.
$^{***}P < 0.01$.
$^{****}P < 0.05$.
ns = not significant.

ratio <25 are of good quality and they readily decompose and release mineral N at a faster rate compared to low-quality residues (C/N > 25). In view of this, leaf litter of *B. balcooa* is a high-quality residue as compared to that of *B. pallida*, the scale leaves were of poor resource quality.

Mineral N dynamics

Nitrate N is the main form of inorganic N in soils under both the bamboo species, whereas the concentration of ammonium-N is much lower. Presumably this is due to high abundance and activity of autotrophic nitrifier population in the soil [20]. Though the soil is slightly acidic, the high concentration of nitrate-N compared to ammonium-N contrasts the theory of Chao *et al.* [20] and Maithani *et al.* [21] that acidity in soil results in decreased activity of autotrophic nitrifiers. The percentage

Table 8.
Relationship between initial chemical composition of litter and fraction of litter N mineralized/immobilized during different time interval ($n = 18$)

Chemical properties (%)	Incubation time (days)		
	30 days	60 days	90 days
C	$y = -31.18 + 0.721x$ $(0.612)^{***}$	$y = 33.13 - 0.561x$ $(-0.259)^{ns}$	$y = -213.19 + 4.737x$ $(0.653)^{**}$
N	$y = 7.25 - 2.949x$ $(-0.897)^{*}$	$y = 6.82 - 0.047x$ $(-0.008)^{ns}$	$y = 34.03 - 15.971x$ $(-0.789)^{*}$
P	$y = -0.104 + 75.602x$ $(0.608)^{***}$	$y = 9.59 - 76.320x$ $(-0.334)^{ns}$	$y = -18.25 + 744.23x$ $(0.971)^{*}$
Lignin	$y = 13.34 - 0.405x$ $(-0.896)^{*}$	$y = 6.87 - 0.005x$ $(-0.006)^{ns}$	$y = 69.70 - 2.294x$ $(-0.825)^{*}$
C/N	$y = -0.084 + 0.075x$ $(0.748)^{*}$	$y = 8.49 - 0.047x$ $(-0.254)^{ns}$	$y = -12.23 + 0.581x$ $(0.942)^{*}$
Lignin/N	$y = -2.29 + 0.262x$ $(0.762)^{*}$	$y = 9.59 - 0.149x$ $(-0.236)^{ns}$	$y = -28.12 + 1.972x$ $(0.930)^{*}$

Values in parentheses are correlation coefficients (r).
* $P < 0.001$.
** $P < 0.002$.
*** $P < 0.005$.
ns = not significant.

contribution of inorganic-N (ammonium + nitrate) to total N in the two bamboo soils is comparable with the range reported by Singh *et al.* [22] who observed that most of the N in the soils they studied was organically bound. After 60 days incubation there was an about 1.5–5 — fold increase in the total inorganic N concentration; however, ammonium-N concentration was not affected, much due to incubation time. This gives an indication of optimum duration of studies which examine mineral-N dynamics in laboratory incubation of soil.

Laboratory net N mineralization

The very low net ammonification rate (2.22–7.78) $\times 10^{-4}$ $\mu g\, g^{-1}\, day^{-1}$ recorded could be attributed to the very low initial ammonium-N in soils under both the species. On the other hand, nitrification rate was higher (0.074–0.351 $\mu g\, g^{-1}\, day^{-1}$) than the reported range of Maithani *et al.* [21] for a subtropical forest re-growth (0.045–0.219 $\mu g\, g^{-1}\, day^{-1}$). There was an about 8–13% increase in ammonification rate in the *B. balcooa* leaf and scale leaf amended soil compared to that of the control. This can be the result of decreased immobilization after 60 days of incubation resulting in increased rate of ammonification. On the contrary, *B. pallida* litter amendment showed a sharp decrease in ammonification relative to control because of increased immobilization after 60 days incubation. Nitrification and net N-mineralization rates were lower in the residue amended soils in general, which could be due to a ready supply of available C to soil microbes resulting in increased

rate of internal N cycling, and excessive heterotrophic immobilization. Moreover, higher C/N and lignin/N ratios in the litter may also result in increased immobilization and, hence, lower N-mineralization rate [19]. Perhaps, this may explain the significantly lower nitrification and mineralization in scale leaf amended soil of *B. pallida* compared to *B. balcooa.* When compared to broadleaved species in regenerating forest stands, the present results show low values with respect to N mineralization, which may be attributed to differences in geology and climatic conditions [19]. Further, all the broadleaved tree residues had a positive role in enhancing the net N mineralization in soil, whereas in this study addition of bamboo foliage into soil did not increase the nutrient mineralization.

Role of residue quality in N-release dynamics

Relative to control, the net N mineralization (at 90 days incubation) rate decreased by 28 and 7% in leaf and scale leaf amendments, respectively, in the case of *B. balcooa.* The decrease was 17 and 76% of that of control in *B. pallida* leaf and scale leaf amended soils. In *B. balcooa*, the reduction in N mineralization was more after the addition of leaf litter than the scale leaves to the soil though in the former, high initial N and low lignin/N was recorded. This indicates that apart from initial N and lignin/N, some other chemical composition in residue (e.g. polyphenols) shall have influenced the N-mineralization in the soil [2]. However, a relatively very low N-mineralization rate in *B. pallida* soil added with scale leaves may be attributed to higher C/N ratio and low initial N [2].

Decomposition of materials with N concentrations of less than 2% (or $C/N > 25$) leads initially to immobilization of mineral N, whereas materials with higher than 2%N (or $C/N < 25$) release mineral N [18]. In our study, leaf litter of *B. balcooa* with 2.28% N and a C/N ratio of 19.54 showed a low rate of immobilization up to 30 days incubation, followed by an increase and then a gradual decrease. The leaf litter of *B. balcooa* with low lignin/N ratio may decompose at faster rate and the 'initial incubation days' referred here may be achieved earlier than one month. The explanation put forward by Myers *et al.* [18] may also hold good in case of other treatments showing immobilization during initial stages. However, the highest immobilization of mineral N from scale leaves of *B. pallida* suggests slower rate of decomposition caused by high lignin/N ratio. This is evinced by the strong positive relationship observed between initial lignin/N ratio and percentage of litter N accumulated/depleted during incubation as well as negative relationship between initial N and percentage depletion of litter N.

Soil respiration (CO_2 evolution)

Soil respiration, considered to be an index of soil metabolism [23] and measured generally in terms of CO_2 $\mu g\, g^{-1}$ of soil is a phenomenon resulted from soil detritus and heterotrophic interaction. In this study, we found a highly significant negative correlation ($P < 0.001$) between CO_2 evolution and incubation time in

litter amendment of both the species. This indicates higher rate of decomposition in the beginning and slowly decreases with the depletion of SOM in the soil as there was no periodic addition of litter as in field conditions. Nevertheless, addition of leaf litter and scale leaves may not have compensated the loss owing to its complexity which resulted in slowing down of the decomposition rate. In both the species, the addition of leaf litter showed lower CO_2 evolution than respective scale leaves amended soil which may be related to the higher lignin and lower carbon concentrations in the former. The significant negative correlation between CO_2 evolution and lignin concentration and positive correlation with carbon also confirm this (Table 7). The same argument may support the slower rate of soil respiration in litter amended soils of *B. balcooa* than in the other species. Ammonification, nitrification and net N-mineralization rates were affected by the rate of soil respiration during incubation and have a negative relationship ($P < 0.001$; Table 7).

Microbial N

The microbial N values observed in the present study were higher than that of a recovering tree-cut subtropical forest (62–126 $\mu g\, g^{-1}$) [24], while comparable to that of a ground-fire affected undisturbed climax forest (156–394 $\mu g\, g^{-1}$) [25]. This indicates the possible influence of climate and soil type on the nutrient immobilization pattern in the microbial component, while it is inferred that the humid tropical soils forms greater microbial N than the subtropical soils. A rapid depletion of microbial N from its initial level was observed in *B. pallida* amendment than that of *B. balcooa*. In this regard the possibility of higher CO_2 evolution affecting microbial activity in the former cannot be ruled out. However, slightly higher microbial biomass N in leaf amended soil of *B. balcooa* than the initial soil sample may indicate possible influence of some other factors which entrusts further research on this aspect. Up to 60 days incubation, a negative relationship ($P < 0.05$) existed between microbial N and nitrogen mineralization whereas after 90 days the relationship became non-significant (Table 7). This indicates that microbial immobilization does not affect current N-mineralization in soil with the increase in incubation time. Initial C, C/N and lignin/N ratios of litter showed a negative relationship with microbial N initially (up to 30 days); thereafter the relationships were positive. An exactly opposite trend was noted in case of initial N and lignin contents in the litter samples (Table 7). Carbon content in the organic residues plays an important role in the dynamics of microbial N [5, 19]. This is substantiated by a strong positive relationship between foliage C and microbial N after 90 days explaining the increase in MBN in litter amended soils.

CONCLUSIONS

It can be concluded that differences in litter quality (particularly in lignin/N) significantly influenced the laboratory N-mineralization and soil respiration during

incubation. The sclerophyllous bamboo foliage when amended resulted in low N mineralization in soils during laboratory incubation as compared to that of the soil only treatment. Even soil respiration and microbial biomass N declined during incubation. It is therefore believed that bamboo foliage of the two study species does not help in improving the soil fertility, mainly due to the low residue quality as compared to most broadleaved tree species, but promoted nutrient immobilization. However, in situ decomposition of bamboo foliage needs experimentation for a meaningful conclusion. Nonetheless, data on N immobilization or mineralization in bamboo species and soils can readily be used in modelling studies to evaluate the long-term effects of organic inputs on soil fertility in these bamboo forests developing through arrested succession in abandoned jhum (slash-and-burn agriculture) fields. We, therefore, recommend that the forest floor of bamboo forests that is especially prone to fire should be protected from fire, predation and any other type of disturbances as it is a major source of soil organic matter. Checks of soil erosion to a greater extent in sloppy degraded lands and the N-poor soils should be amended with high quality residues in order to sustain soil productivity.

Acknowledgements

The authors are thankful to CSIR and DST (New Delhi) and ICFRE (Dehra Dun) and GBPIHED (Almora) for financial assistance. The authors are thankful to the anonymous reviewer whose comments helped in improving the quality of the paper.

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