Changes in soil biochemical properties following replacement of Banj oak forest with Chir pine in Central Himalaya, India

Vijyeta Manral, Kiran Bargali, S. S. Bargali* and Charu Shahi

Abstract

Introduction: In Central Himalaya, anthropogenic activities have led to the widespread replacement of Banj oak (*Quercus leucotrichophora*) forest by Chir pine (*Pinus roxburghii*) for decades. This study was conducted to determine how natural Banj oak, Chir pine, and mixed oak-pine forest would differ in soil microbial biomass and soil nutrients. Soil microbial biomass nitrogen (SMBN) and phosphorus (SMBP), soil organic carbon (SOC) total nitrogen (TN), and total phosphorus (TP) in the 0 to 15 cm soil layer were investigated in the Central Himalayan region in the stands of Banj oak, mixed oak-pine, and Chir pine forest.

Results: The SMBN and SMBP were significantly higher in Banj oak and mixed oak-pine forest as compared to Chir pine forest. The ratios of SMBN to TN (SMBN/TN) and SMBP to TP (SMBP/TP) were significantly higher in the Chir pine forest, indicating that in this forest, the proportion of microbial biomass N and P to total soil N and P was higher as compared to Banj oak forest. A similar pattern of variation was found in relation to season across the forests, all with an apparent peak in the rainy season.

Conclusion: These results indicate that low microbial biomass N and P may be one of the reasons to create a nutrient poor site in Chir pine forest. The collection of pine litter by local people also impairs the return of nutrients to the soil and makes it difficult for Banj oak to re-invade areas occupied by Chir pine. This calls for cautions in large-scale conversions of the Banj oak forests to coniferous plantations as a forest management practice on concerns of sustaining soil productivity.

Keywords: Soil microbial biomass nitrogen (SMBN), soil microbial biomass phosphorus (SMBP), Forest types, Chloroform fumigation and extraction method (CFE), Altitude

Introduction

In Indian Central Himalaya, Banj oak (*Quercus leucotri-chophora* A. Camus) and Chir pine (*Pinus roxburghii* Sarg.) are the two predominant evergreen forests occurring between 1200 and 2200 m altitudes (Manral 2018). The Banj oak is associated with more mesic- and nutrient-rich sites while the sites of the Chir pine are often moisture- and nutrient-deficient (Bargali and Bargali 2000) thus influence the microclimate of the area (Joshi and Bargali 1992). Several studies (Singh et al. 1984; Singh and Singh 1992; Singh and Bisht 1992; Bargali et al. 2015) have reported that Chir pine is replacing Banj oak, and although under natural succession, it should be the reverse. This reverse succession is not natural, but rather due to various forms of human-caused disturbances such as lopping, logging, fire, and grazing. Banj oak is also exploited for litter collection used as animal bed and composting by local inhabitants. Due to these site disturbances, Banj oak is failing to regenerate in many areas and Chir pine is rapidly encroaching upon the Banj oak forests (Saxena and Singh 1984). Mixed oak-pine forest represents an intermediate situation between these two forest types. By determining the quantity and quality of organic matter

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inputs, forest types affect soil microbial biomass and activities (Xu et al. 2008, Yang et al. 2010). Changes in plant community composition may affect soil organic carbon (SOC) dynamics as a result of changes in the amount and chemical composition of plant residues returned to the soil (Yang et al. 2010, Padalia et al. 2018), which in turn influences the pool size and activity of the soil microbial biomass (Kasel and Bennett 2007). Singh et al. (1984) also reported that replacement of Banj oak forest with Chir pine in the Himalaya affects the nitrogen cycle.

Soil microbial biomass regulates the carbon and nitrogen cycle in terrestrial ecosystems and also plays a key role in the conversion and supply of nutrients (Berg and Smalla 2009). Microbial biomass N and P constitutes a significant part of the potentially mineralizable N and P that is available to plants (Singh et al. 1991). Hence, soil microbial biomass, a labile fraction of the soil organic matter, has long been suggested to be a significantly more sensitive indicator of changing soil conditions than the total soil organic matter content (Jenkinson and Powlson 1976).

In this study, soil microbial biomass N (SMBN), microbial biomass P (SMBP), and relationships between soil properties and soil microbial biomass in 0–15 cm soil layer were compared between the forests of Banj oak, mixed oak-pine, and Chir pine in Central Himalayan region of India previously studied for soil microbial carbon (Bargali et al. 2018). The objectives of this study were to investigate: (1) How do the three major forest types would differ in SMBN, SMBP, and soil nutrients? (2) How do SMBN and SMBP vary seasonally and annually for three forest types under temperate climatic conditions? We hypothesize that the Chir pine forest would have markedly lower soil microbial biomass, hence slower nutrient cycling than the Banj oak and mixed oak-pine forest because of the slower rate of litter decomposition.

Materials and methods
Site description
This study was conducted in the Central Himalayan region near Nainital town of Uttarakhand State, India. Three forest types viz., *Quercus leucotrichophora* A. Camus (Banj oak), *Pinus roxburghii* Sarg. (Chir pine), and mixed oak-pine were selected between 800 and 2000 m above mean sea level (29°19′–29°28′ N and 79°22′–79°38′ E). In each forest, sample plots were set up in three stands at three positions viz. hill base (HB), hill slope (HS), and hill top (HT), and in each of the stands, three 20 × 20 m plots were established. All the sites have mature forests with uneven-aged trees.

Climate
The climate of study area is montane, temperate, and monsoon type (Singh and Singh 1992) and governed by the monsoon rhythms. There are three distinct seasons comprising, i.e., summer (March–May), rainy (June–October), and winter (November–February). March and November are the transitional months and can be recognized as spring and autumn, respectively. Mean monthly maximum temperature ranged from 11 to 26 °C and mean monthly minimum from 4 to 17 °C. Annual rainfall of the area was 2347 mm and near about 80% occurs during mid-June to mid-September.

Geology
Geologically, the study sites were located in the lesser Himalayan zone. The rocks of the lesser Himalaya are complex mixture of sedimentary, low grade metamorphosed, and igneous rocks and belong to Krol series (Valdiya 1980). A sequence of limestones, gray and greenish-gray and purple slates, siltstones and in the upper part massive dolomites that follow the Blaini without perceptible break was named by Medlicott (Medlicott 1864) as the Krol series after the Krol mountains. The Baliani rock consists of conglomerates, siltstones. Krol formation consists predominantly of carbonates, limestones, marl, and slates in the lower part and dolomites on the upper part (Valdiya 1980).

Soil sampling and chemical analysis
Soil samples were collected from each plot in triplicate by removing monoliths (10 × 10 × 15 cm) at seasonal interval from upper soil depth by removing the litter. The composited soils were divided into two parts: one was sieved to pass through a 2-mm mesh immediately and stored at 4 °C until analysis for the estimation of SMBN and SMBP, and the other was air-dried and used for estimation of soil physico-chemical properties. Soil microbial biomass nitrogen (SMBN) was determined by a chloroform fumigation-extraction (CFE) method as proposed by Brookes et al. (1985).

For each site, three out of six sub-samples (each 10.0 g fresh soil) were fumigated with ethanol-free chloroform. The other (not fumigated) portion was taken in a crucible and placed in separate desiccator without chloroform. The desiccators were covered and kept in dark at room temperature for 5 days (Anderson and Ingram 1998). After the fumigant was removed, fumigated and non-fumigated soils were extracted with 0.5 M K_2SO_4. The total nitrogen contents (inorganic + organic) of the K_2SO_4 extracts of fumigated and non-fumigated soils were measured after Kjeldahl digestion method (Brookes et al. 1985) as follows:

$$SMBN\left(\mu g\ g^{-1}\right) = \frac{TN(F)\text{-}TN(NF)}{K_c}$$

where TN = total nitrogen, F = fumigated soil, NF = non-fumigated soil, and Kc = 0.54 (factor given by Brookes et al. 1985).

Soil microbial biomass phosphorus (SMBP) was determined by the CFE method (Brookes et al. 1982). Soil MBP was calculated as $NaHCO_3$ extractable Pi from fumigated soil minus that extracted from non-fumigated soil and divided by a (fraction of biomass phosphorus extracted after fumigation) value of 0.40 (Brookes et al. 1982) according to the following formula:

$$SMBP\left(\mu g\ g^{-1}\right) = \frac{TP(F)\text{-}TP(NF)}{K_p}$$

where TP = total phosphorus, F = fumigated soil, NF = non-fumigated soil, and Kp = 0.40 (factor given by Brookes et al. 1982)

Statistical analysis

The statistical analyses were conducted with SPSS 16.0. A three-way analysis of variance (ANOVA) was used to test the effects of forest type, sampling season, and year on soil microbial biomass and soil chemical properties. Pearson's correlation analysis was used to determine whether there were significant interrelationships among the measured properties of the soils. Multivariate relationships between variables were analyzed using principal component analysis (PCA).

Results

Soil physical characteristics

Details about the physico-chemical properties of soil have already been described in Bargali et al. (2018). Across the sites, the sand percentage varied from 70 (mixed oak-pine forest) to 80 (Chir pine forest). The water holding capacity ranged from 36.65 (Chir pine forest) to 51.50% (Banj oak forest). The maximum bulk density ($1.12\ g\ cm^{-3}$) was recorded in Chir pine forest and minimum ($0.42\ g\ cm^{-3}$) in mixed oak-pine forest while soil moisture was maximum (22.48%) in mixed oak-pine forest and minimum (7.36%) in Chir pine forest. The analysis showed that soils in all the three forest sites were acidic with a range of pH from 5.37 to 6.63.

Soil nutrients

Analysis of variance (ANOVA) showed that total C, N, and P for the top layer increased significantly ($P < 0.01$) after forest type changed from Banj oak to mixed oak-pine and then declined sharply in Chir pine forest. Across the season and altitude, the mean TN in the mixed oak forest was 1.49 times of those in the Banj oak forest and 3.59 times of those in the Chir pine forest.

Similarly, the mean TP in the mixed oak-pine forest was 1.23 and 1.93 times of those in the Banj oak and Chir pine forest. The C:N, C:P, and N:P ratios were higher in Chir pine forest (Table 1).

Soil microbial biomass nitrogen (SMBN) and phosphorus (SMBP)

The SMBN was 67 to $105\ mg\ kg^{-1}$ for Banj oak forest and 92 to $143\ mg\ kg^{-1}$ in mixed oak-pine forest, while it was much lower (55 to $90\ mg\ kg^{-1}$) in Chir pine forest (Fig. 1). The SMBP ranged from 20 to $53\ mg\ kg^{-1}$ in Banj oak forest, from 22 to $72\ mg\ kg^{-1}$ in mixed oak-pine forest, and from 12 to $43\ mg\ kg^{-1}$ in Chir pine forest. In general, the maximum value of SMBN and SMBP was recorded during the first year as compared to the second year but the differences were statistically not significant. Soil microbial biomass N and P increased significantly (ANOVA, $P < 0.01$) from Banj oak forest to mixed oak-pine forest and declined in Chir pine forest. The seasonal pattern of SMBN and SMBP were similar in all the three forest types, the values being maximum during rainy and minimum during the winter season (Fig. 1).

An analysis of variance on the pooled data for 2 years indicated that differences in SMBN and SMBP in the three forests were significant at $P < 0.01$ while the effects of season and position were insignificant (Supplementary Table 1).

Relationships between microbial N and P and soil properties

The correlation coefficients for relationships between the soil physico-chemical characteristics are given in Supplementary Table 2. Most of the soil properties are significantly correlated with each other. Across the sites, SMBN and SMBP were positively related to soil organic C, N, and P, silt and clay percentage, moisture content, and water holding capacity while bulk density and sand percentage are negatively related. No significant effect of soil pH was observed on soil microbial biomass (Supplementary Table 2).

SMBP was positively related to SMBN according to the following formula:

$$SMBP = \text{-}31.42 + 0.754\ SMBN\ \left(r^2 = 0.910, P < 0.01\right)$$

Microbial to soil nutrient ratios

The proportion of microbial biomass N of the total soil N (SMBN/TN) ranged from 3.36 to 7.61% in Banj oak forest and 7.04 to 16.11% in Chir pine forest while the proportion of microbial biomass P of the total soil P (SMBP/TP) ranged from 6.2 to 13% in Banj oak forest and 13 to 39% in Chir pine forest (Fig. 2). The SMBN/TN and SMBP/TP represent the availability of nitrogen

Table 1 Soil chemical properties in different forest types (means ± 1 S.E.)

Soil nutrients	Position	Rainy			Winter			Summer		
		BO	CP	OP	BO	CP	OP	BO	CP	OP
C_{org} (%)	HT	1.70 ± 0.03	1.24 ± 0.00	3.24 ± 0.04	1.14 ± 0.01	1.03 ± 0.02	3.03 ± 0.03	1.38 ± 0.04	1.13 ± 0.01	3.10 ± 0.05
	HS	2.45 ± 0.04	1.15 ± 0.01	3.75 ± 0.07	2.11 ± 0.00	1.02 ± 0.01	3.32 ± 0.05	2.27 ± 0.02	1.05 ± 0.02	3.50 ± 0.06
	HB	2.75 ± 0.07	2.14 ± 0.00	5.24 ± 0.09	2.29 ± 0.06	1.80 ± 0.03	4.76 ± 0.02	2.50 ± 0.02	1.97 ± 0.06	5.11 ± 0.04
N_{total} (%)	HT	0.11 ± 0.02	0.06 ± 0.01	0.17 ± 0.01	0.10 ± 0.02	0.03 ± 0.01	0.13 ± 0.02	0.10 ± 0.02	0.05 ± 0.01	0.15 ± 0.02
	HS	0.21 ± 0.01	0.07 ± 0.01	0.38 ± 0.01	0.15 ± 0.02	0.05 ± 0.01	0.32 ± 0.01	0.19 ± 0.02	0.06 ± 0.00	0.34 ± 0.02
	HB	0.30 ± 0.01	0.12 ± 0.01	0.38 ± 0.01	0.25 ± 0.01	0.10 ± 0.02	0.33 ± 0.01	0.28 ± 0.01	0.11 ± 0.02	0.37 ± 0.01
P_{total} (%)	HT	0.30 ± 0.00	0.01 ± 0.00	0.04 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.03 ± 0.00
	HS	0.06 ± 0.00	0.02 ± 0.00	0.06 ± 0.00	0.03 ± 0.00	0.01 ± 0.00	0.04 ± 0.00	0.05 ± 0.00	0.01 ± 0.00	0.04 ± 0.00
	HB	0.08 ± 0.00	0.02 ± 0.00	0.10 ± 0.00	0.04 ± 0.00	0.01 ± 0.00	0.07 ± 0.00	0.06 ± 0.00	0.01 ± 0.00	0.07 ± 0.00
C:N ratio	HT	15.4	20.7	19.0	11.4	34.33	23.3	13.8	22.6	20.7
	HS	11.7	16.4	9.8	14.7	20.4	10.4	11.9	17.5	10.29
	HB	9.2	17.8	13.8	9.2	18.0	14.4	8.9	17.9	13.8
C:P ratio	HT	56.7	124.0	81.0	57.0	103.0	151.5	69.0	113.0	103.0
	HS	40.8	57.5	62.5	70.3	102.0	83.0	45.4	105.0	87.5
	HB	34.4	107.0	52.4	57.2	180.0	68.0	41.7	197.0	73.0
N:P ratio	HT	3.9	6.8	4.5	5.1	3.6	7.0	5.2	5.6	5.0
	HS	3.62	3.65	6.33	5.1	5.5	8.0	3.8	5.6	8.5
	HB	3.8	6.2	3.9	6.5	10.5	4.7	4.8	11.1	5.3

HT hill top, *HS* hill slope, *HB* hill base, *BO* Banj oak, *CP* Chir pine, *OP* oak-pine

and phosphorus in the soil. The significantly higher ratios indicate that soil in Chir pine forest reduces the rate of litter decomposition and immobilizes available N and P in microbial biomass. The low nutrient availability caused by the immobilization of nutrients in microbial biomass intensifies the nutrient deficiency in Chir pine forest as indicated by lower concentration of nitrogen and phosphorus in the soil. Across the seasons, the microbial quotients were lower in the rainy season and higher in winter or summer season. Across the positions, higher microbial quotients were recorded in hill top and lower ratios were obtained in hill base (Fig. 2).
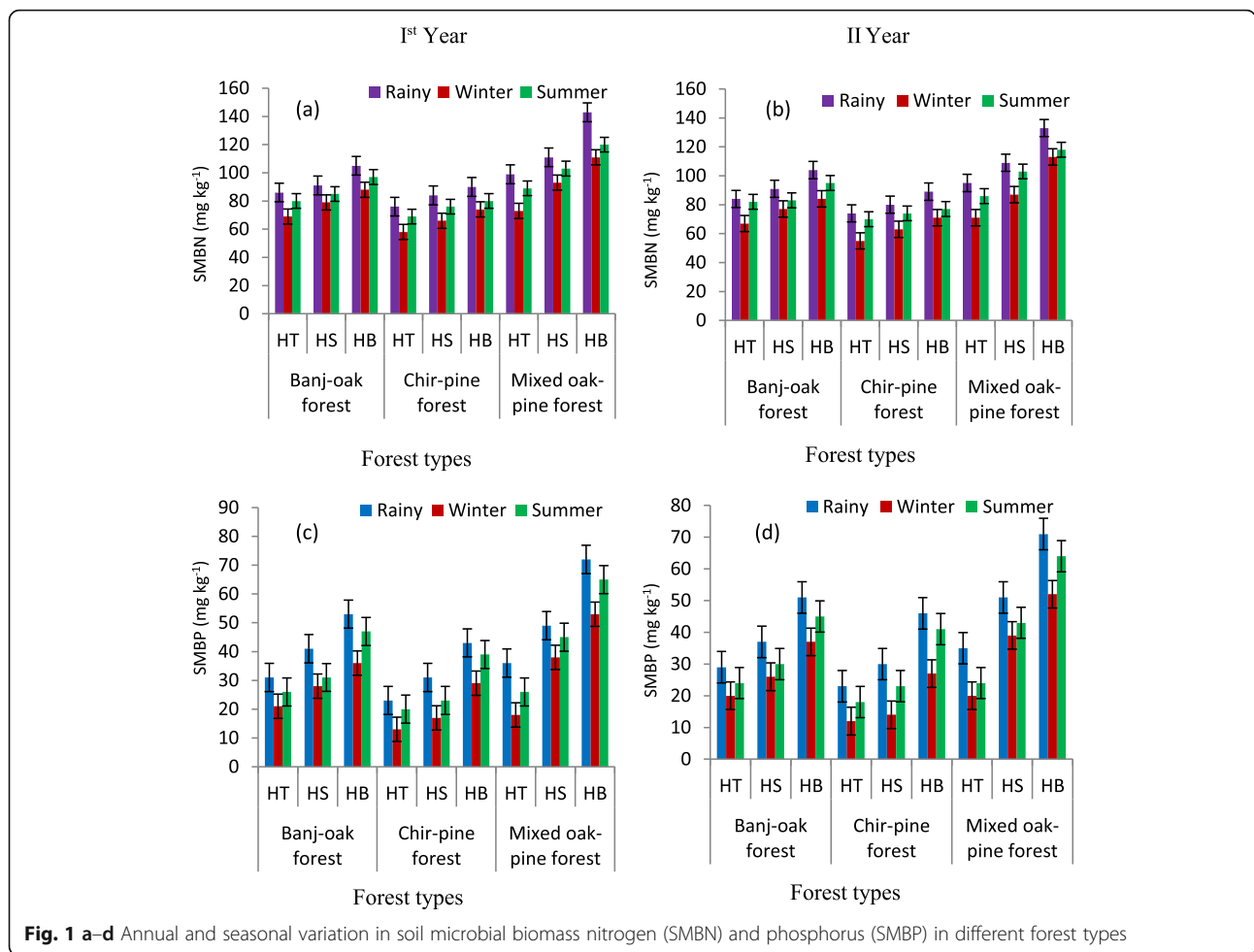
Discussion
Soil physical and chemical properties
The three forest types differ remarkably in soil physico-chemical properties. Due to the variation in topography, climate, weathering processes, vegetation cover, microbial activities, season, and other biotic and abiotic factors, the physico-chemical properties of soil vary within space and time (Bargali et al. 1993a). Therefore, soil properties vary within short distances in the Himalayan regions (Baumler 2015). Mixed oak-pine forest was rich in all the estimated soil properties as compared to Banj oak and Chir pine forests. Baumler (2015) stated that floristic composition plays an important role in the formation of soil organic matter and influences fundamental soil-forming processes. The texture of soil may also

affect the productivity of the forest by affecting moisture availability and nutrient supply to microbial decomposition (Dorji et al. 2009; Dorji and Baumler 2013; Baumler 2015).

Factors affecting microbial biomass N and P
Our results suggested that the mixed oak-pine forests would be of advantage to sustain soil fertility possibly due to a high tree density and a greater quantity of litters in these soils (Manral 2018). Soil microbes are affected by soil environmental conditions, changes in vegetation, land use (Stevenson et al. 2016), and litterfall (Ehlers et al. 2010), and then all these factors affect the decomposition processes (Aponte et al. 2010). According to Yang et al. (2010), soil microbial biomass greatly depends on soil organic matter as a substrate. Thus, the higher microbial biomass in the mixed oak-pine forest stands is mainly attributable to the greater availability of organic matter in these stands. This is also evident from the significant positive correlations between soil microbial nutrients (N and P) and soil organic carbon (Supplementary Table 2). Soil moisture also plays an important role in the physiological attributes in forest ecosystems and litter decomposition (Bargali et al. 1993b; Bargali 1996), and hence influences the soil microbial biomass as indicated by strong positive correlation between SMBN, SMBP, and soil moisture (Supplementary Table 2). In Chir pine forest, open canopy resulted in excessive

Fig. 1 a–d Annual and seasonal variation in soil microbial biomass nitrogen (SMBN) and phosphorus (SMBP) in different forest types
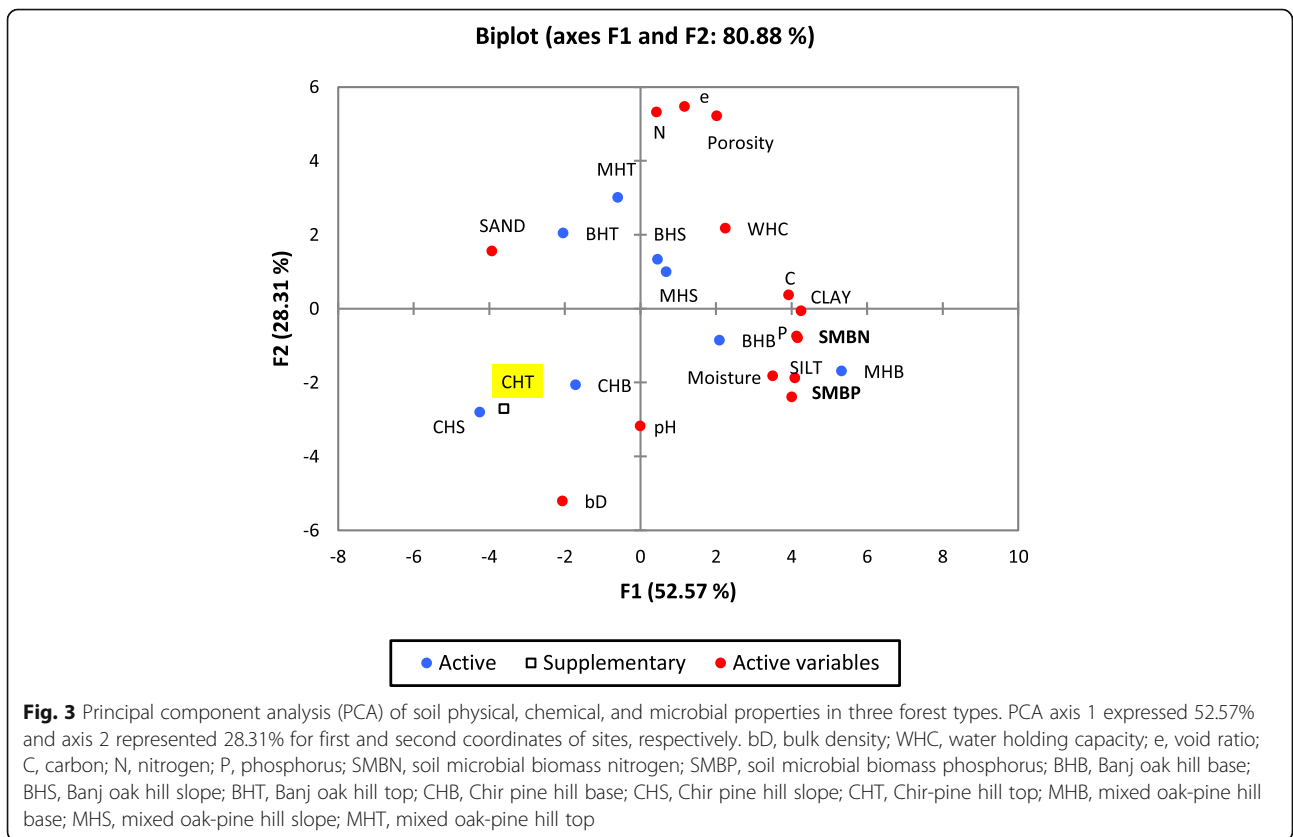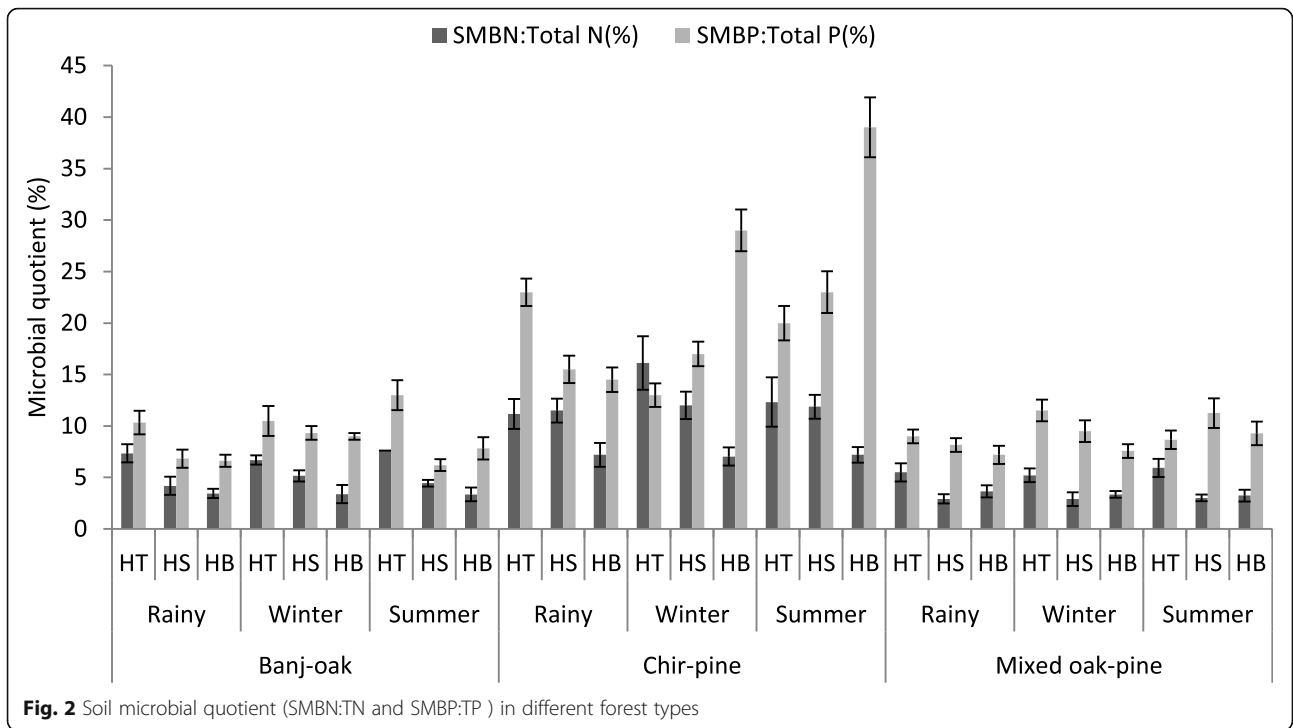
loss of soil moisture and reduced the SMBN and SMBP. Another reason might be the slow decomposition rate of pine litter which releases the nutrients in a very slow rate (Upadhyay and Singh, 1989) resulting in enhanced soil compaction and reduced available pore space for microbes (Joshi et al. 1997; Bargali et al. (2019).

In comparison to the Banj oak forest and mixed oak-pine forest, the soil organic matter in Chir pine forest declined due to the removal of pine litter by the local inhabitants (Manral 2018) and poor litter quality and quantity as pine litter contain a large amount of recalcitrant compounds that lead to lower rate of decomposition (Usman et al. 2000) and consequently slower transformation of particulate organic matter into mineral soil compounds resulting in low microbial biomass. Singh et al. (1990) stated that the microbial population is more related to site-specific conditions that could be influenced by respective leaf litter.

There were distinct seasonal variations in microbial biomass with a trough during the winter season and a peak during the rainy season. During the rainy season, increased temperature and moisture significantly promote the growth of soil microbes (Edwards and Jefferies 2013). Therefore, the partial immobilization of nutrients as microbial biomass might represent the immediate input of available nutrients into these forest soils for plant growth (Bargali and Bargali 2000). We observed a decrease in average microbial biomass with the increase of elevation because soil microbial biomass variables are primarily determined by soil properties such as soil texture, soil moisture, soil organic matter, and soil nutrients which are further controlled by environmental factors. Higher soil moisture content, less exposure to sunlight, higher plant diversity, rich substrate, and leaching of nutrients from higher elevations (hill top and slope) resulted in better growth of microbes at hill base. The principal component analysis (PCA) was performed to discriminate different forest types on the basis of physico-chemical properties of soil as well as microbial biomass nitrogen and phosphorus (Fig. 3). PCA analysis indicated that F1 and F2 components explained the maximum variance with respect to different soil parameters and their cumulative percentage of variance was 81% (Supplementary Table 2).

Fig. 2 Soil microbial quotient (SMBN:TN and SMBP:TP) in different forest types

Fig. 3 Principal component analysis (PCA) of soil physical, chemical, and microbial properties in three forest types. PCA axis 1 expressed 52.57% and axis 2 represented 28.31% for first and second coordinates of sites, respectively. bD, bulk density; WHC, water holding capacity; e, void ratio; C, carbon; N, nitrogen; P, phosphorus; SMBN, soil microbial biomass nitrogen; SMBP, soil microbial biomass phosphorus; BHB, Banj oak hill base; BHS, Banj oak hill slope; BHT, Banj oak hill top; CHB, Chir pine hill base; CHS, Chir pine hill slope; CHT, Chir-pine hill top; MHB, mixed oak-pine hill base; MHS, mixed oak-pine hill slope; MHT, mixed oak-pine hill top

Fractions of soil nutrients in the microbial biomass

The fractions of soil nutrients in soil microbial biomass vary substantially across forest types; mixed-oak pine forest has the lowest, while Chir pine forest has the highest fraction of total soil nitrogen and phosphorus in microbial biomass (Table 2). Singh et al. (1984) reported that Banj oak maintained soil fertility through the nutrient-rich litter and rapid mineralization. Due to anthropogenic disturbances like heavy lopping of Banj oak for fodder and fuel resulted in low leaf litter input and nutrient return and make the site suitable for invasion by Chir pine. Patel et al. (2010) reported 1.37–4.72% microbial N/total N and 1.99–15.61% microbial P/total P, and Qi et al. (2018) reported 2.21–9.49% microbial N/total N and 0.12–5.56% microbial P/total P for soils under different land-use systems. The global average estimates of contributions of soil microbial biomass to total N and total P are 2.6 and 8.0% (Xu et al. 2013). This study reported a wide range in the fractions of total soil elements contained in soil microbial biomass. The fraction of soil total N in soil microbial biomass could be as low as 2.9% and as high as 16.0%, while the fraction of soil total P in soil microbial biomass could be as low as 6.2% and as high as 39.9%. This suggests that in these forests, soil microbial biomass was an important pool of N and P in the soil, and microorganisms were actively involved in the nutrient cycling as well as supply for plants.

There is a contrasting enriching gradient for two elements; a high-concentration element has a low fraction in soil microbial biomass; and compared to P, N has the highest concentration in soils but the lowest fraction in soil microbial biomass (Table 2). The proportion of SMBN to TN and SMBP to TP varied with seasons, attaining higher values in the winter season and lower in rainy season indicating higher immobilization of nutrients in the winter season. Across the altitude, the soil microbial quotient increased with increasing altitude denoting the presence of a less active nutrient pool in the high altitude soil. In this study, the average SMBN to SMBP ratio was maximum for Chir pine forest which indicated nutrient-limited conditions in Chir pine forest. There are significant linear correlations between N and P in soils and soil microbial biomass (Fig. 4).

Changes in soil microbial biomass as an indicator for nutrient limitation

Xu et al. (2013) suggested that soil microbial biomass N:P ratio can be used as an indicator for nutrient limitation since N:P ratio in microbial biomass is more constrained than the plant and soil N:P ratio. This is based on the assumption that a higher N:P ratio than an optimal value indicates a P deficiency for plant acquisition, and vice versa. Across forest types, the varied fractions of soil elements in soil microbial biomass may imply N or P limitation in specific forest type because soil microbes are more efficient in obtaining nutrients than plants from soil to keep their own biological mechanisms functioning well (Bardgett et al. 2003). In nutrient-depleted ecosystems, the relatively high fraction of specific nutrients in microbial biomass implies a strong limitation of this element to plants (Jonasson et al. 1999). For example, Chir pine forest, a severe N- and P-limiting forest ecosystem, has a large fraction of soil total N and P in microbial biomass (Table 2) while Banj oak and mixed oak-pine forest has a comparatively small fraction of soil total N and P in microbial biomass. The N:P ratio in microbial biomass was much lower than those in the soils (Table 2). When availability of P in the system decreased, relatively more P will be stored in soil microbial biomass enhancing the P limitation for plants. This results in a relatively lower microbial N:P ratio and higher soil N:P ratio. Wan et al. (2015) suggested that tree species are responsible for the variation in nutrient stoichiometry in soil and microbial biomass because differences of plant species and diversity can change nutrient use efficiency and competition for nutrients.

Conclusions

We concluded that the Banj oak and mixed oak-pine forests have the high concentrations of N and P in soils and microbial biomass indicating a higher amount of soil microorganisms and substrate utilization efficiency as compared to Chir pine forest. High microbial quotients in Chir pine forest indicate a marked immobilization of N

Table 2 Summarized percentage of soil elements contained in soil microbial biomass

Forest type	Nmic/Ntot (%)	Pmic/Ptot (%)	N:P ratio in soil	N:P ratio in microbial biomass	Reference
Banj oak	5.07 (3.36–7.61)	8.84 (6.20–13.0)	4.66 (3.62–6.47)	2.59 (1.98–3.28)	Present study
Mixed oak-pine	3.97 (2.90–5.93)	9.12 (7.20–11.50)	5.91 (3.90–8.50)	2.47 (1.85–3.42)	Present study
Chir pine	10.71 (7.04–16.11)	21.55 (13.0–39.0)	6.60 (3.60–11.10)	3.08 (2.05–4.46)	Present study
Temperate coniferous forest	2.62 (2.29–3.00)	4.31 (2.85–6.51)	15.20 (11.10–20.90)	4.40 (3.60–5.40)	Xu et al. (2013)
Temperate broadleaf forest	2.42 (2.08–2.81)	8.60 (6.22–11.89)	19.90 (16.30–24.20)	6.90 (6.00–7.90)	Xu et al. (2013)
Mixed forest	2.80 (2.61–3.02)	6.72 (5.61–8.04)	15.70 (14.10–17.50)	4.80 (4.20–5.40)	Xu et al. (2013)
Cropland	1.78 (0.92–3.87)	4.19 (2.86–5.63)	6.18 (3.11–10.57)	2.49 (1.44–5.46)	Bargali et al. (2019)
Mixed plantation	2.60 (0.74–5.03)	5.59 (3.43–7.62)	5.34 (3.23–8.43)	2.27 (1.07–3.98)	Bargali et al. (2019)

Nmic microbial nitrogen, *Ntot* total soil nitrogen, *Pmic* microbial phosphorus, *Ptot* total soil phosphorus
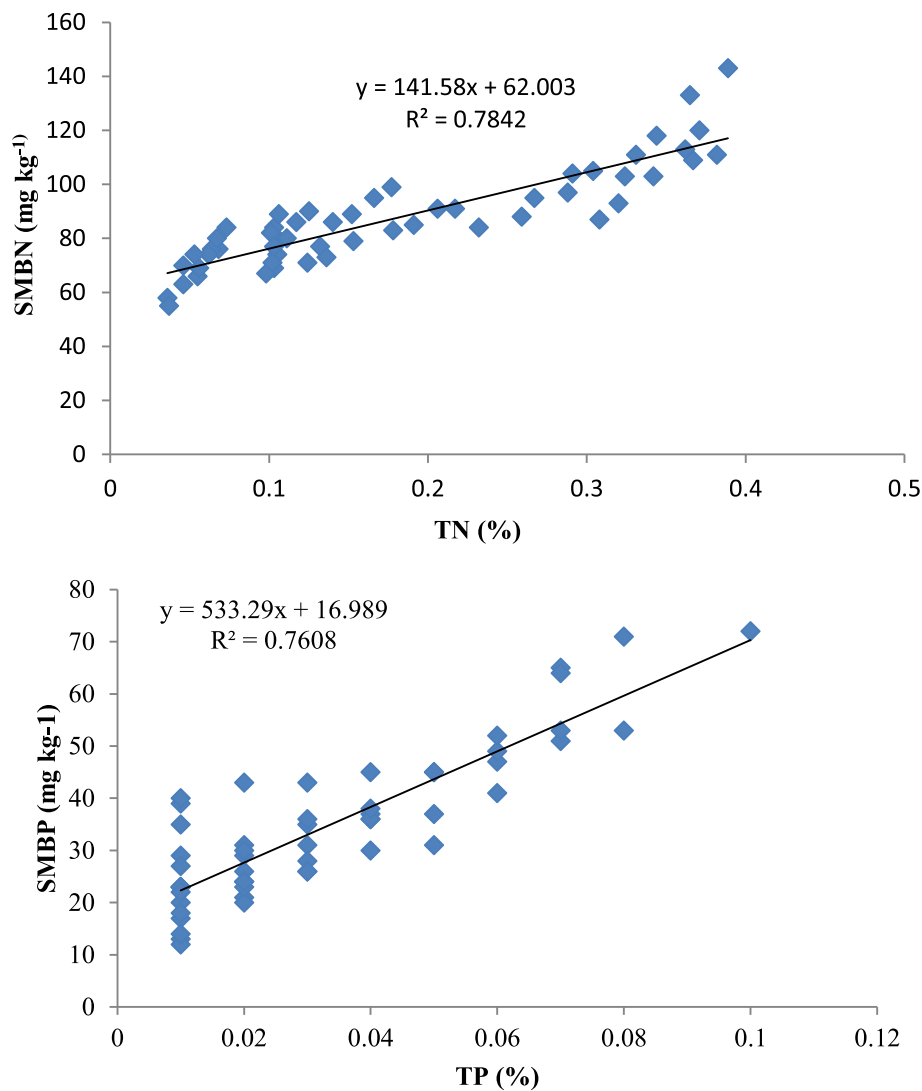
Fig. 4 Relationship between soil TN and SMBN and soil TP and SMBP for *n* = 54, i.e., three forests × three position × three seasons × 2 years

and P in the microbial biomass. Collection of pine litter by local people leads to a short residence time of litter on the ground and result in low in situ decomposition. This process also impairs the return of nutrients to the soil. This indicates that the creation of shortage of major soil nutrients (N and P) enables Chir pine to resist reinvasion by Banj oak. This calls for the implementation of proper forest management practices to prevent large-scale conversion of the native Banj oak forests to Chir pine forest on concerns of sustainable soil productivity.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s13717-020-00235-8.

Additional file 1: Table S1. ANOVA showing effect of forest types on soil physical, chemical and microbial properties. **Table S2.** Pearson's

correlation between soil microbial biomass nitrogen (SMBN) and phosphorus (SMBP) and soil physical and chemical properties

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