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 leucotrichophora 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...
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 Balani 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 K2SO4. The total nitrogen contents (inorganic + organic) of the K2SO4 extracts of fumigated and non-fumigated soils were measured after Kjeldahl digestion method (Brookes et al. 1985) as follows:
mixed oak forest was 1.49 times of those in the Banj oak. Across the season and altitude, the mean TN in the pine and then declined sharply in Chir pine forest. After forest type changed from Banj oak to mixed oak-pine forest, the maximum bulk water holding capacity ranged from 36.65 (Chir pine forest) to 80 (Chir pine forest). The sand percentage varied from 70 to 80% in Banj oak forest, and from 12 to 39% in Chir pine forest (Fig. 2). The SMBN/SMBP ratio ranged from 6.2 to 13% in Banj oak forest and 7.04 to 16.11% in Chir pine forest while 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).

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:

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

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
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 physicochemical 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 litter 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

## 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     |
| Corg (%)      | 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    |
| CP 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
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 Jeffries 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).
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.

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).

| 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

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
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.

**Abbreviations**

bD: Bulk density; BHB: Banj oak hill base; BHS: Banj oak hill slope; BHT: Banj oak hill top; BO: Banj oak; CP: Chir pine; CHB: Chir pine hill base; CHS: Chir pine hill slope; CHT: Chir pine hill top; C: Carbon; e: Void ratio; NMHB: Mixed oak-pine hill base; MHS: Mixed oak-pine hill slope; MHT: Mixed oak-pine hill top; N: Nitrogen; P: Phosphorus; PCA: Principal component analysis; OP: Oak-pine; SMBN: Soil microbial biomass nitrogen; SMBP: Soil microbial biomass phosphorus; WHC: Water holding capacity

**Acknowledgements**

We are thankful to the Head, Department of Botany, for providing necessary lab facilities and Tea Development Board, Bhowali, Nainital, for providing lab facilities for chemical analysis. We are thankful to Dr Haripriya Pathak, Assistant Professor (English), for the detailed English review. We thank both the reviewers, concerned editors, and Professor Jiquan Chen for their closer look into the article and valuable suggestions made.

**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
Authors’ contributions

VM collected and analyzed the data and KB played a major role in writing the manuscript. SSB guided the research regarding spatial data analysis and reviewed and CS done the analysis. All authors read and approved the final manuscript.

Funding

Not applicable

Availability of data and materials

The data used during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 14 March 2020 Accepted: 21 May 2020

Published online: 08 June 2020

References

Anderson JM, Ingram JSI (1998) Tropical soil biology and fertility. A Handbook of Methods, pp 1–221

Aposte C, Maranon T, Garcia LV (2010) Microbial C, N and P in soils of Mediterranean oak forest: influence of season, canopy cover and soil depth. Biogeochemistry 101:77–92

Bardgett RD, Streeter TC, Bol R (2003) Soil microbes compete effectively with plants for organic-nitrogen inputs to temperate grasslands. Ecology 84:1277–1287

Bargali K, Bargali SS (2000) Nutrient utilization efficiencies of two Central Himalayan tree species. J Trop For Sci 12:450–458

Bargali K, Joshi B, Bargali SS, Singh SP (2015) Oaks and the biodiversity they sustain. International Oaks 26:65–76

Bargali K, Manral P, Padalia K, Bargali SS, Upadhyay VP (2018) Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. Catena 171:125–135

Bargali SS (1996) Weight loss and nitrogen release in decomposing wood litter in an age series of eucalypt plantation. Soil Biol Biochem 28:699–702

Bargali SS, Padalia K, Bargali K (2019) Effects of tree foddering on soil health and microbial biomass under different land use systems in the central Himalayas. Land Degrad Dev 30(16):1984–1998

Bargali SS, Singh RP, Joshi M (1993b) Changes in soil characteristics in eucalypt plantations replacing natural broad leaved forests. J Veg Sci 4:25–28

Bargali SS, Singh SP, Singh RP (1993a) Pattern of weight loss and nutrient release in decomposing leaf litter in an age series of eucalypt plantations. Soil Biol Biochem 25:1731–1738

Baumler R (2015) Soils. In: Miehe S, Pendry CA (Eds.), Nepal: An introduction to the natural history, ecology and human environment in the Himalayas – a companion to the flora of Nepal. The Royal Botanical Garden Edinburgh, pp. 125–134

Berg G, Smalla K (2009) Plant species and soil type cooperatively shape the structure and function of microbial communities in the rhizosphere. FEMS Microbiol Ecol 68(1):1–13

Brookes PC, Kragt JF, Powson DS, Jenkinson DS (1985) Chloroform fumigation and release of soil nitrogen: the effect of fumigation time and temperature. Soil Biol Biochem 17:831–835

Brookes PC, Powson DS, Jenkinson DS (1982) Measurement of microbial biomass phosphorus in soil. Soil Biol Biochem 14:319–329

Dorji KD, Baumler R (2013) Soils as proxies of the history of landscape and climate: examples from eastern Bhutan. J Nepal Geol Soc 46:19–24

Dorji T, Caspari T, Baumler R, Veldkamp A, Tshering Kado Dorji T, Bailee I (2009) Soil development on Late Quaternary river terraces in a high montane valley in Bhutan, Eastern Himalayas. Catena 78:48–59

Edwards KA, Jefferies RL (2013) Inter-annual and seasonal dynamics of soil microbial biomass and nutrients in wet and dry low-Arctic sedge meadows. Soil Biol Biochem 57:83–90

Ehlers K, Bakken LR, Frostegard A, Frossard E, Bonenmann EK (2010) Phosphorus limitation in a Feralsol: impact on microbial activity and cell internal P pools. Soil Biol Biochem 42:558–566

Jenkinson DS, Powson DS (1976) The effects of biocidal treatment on metabolism in soil. V. A method for measuring soil biomass. Soil Biol Biochem 8:209–213

Jonasson S, Michelsen A, Schmidt K (1999) Coupling of nutrient cycling and carbon dynamics in the Arctic integration of soil microbial and plant processes. Appl Soil Ecol 11:135–146

Joshi M, Bargali K, Bargali SS (1997) Changes in physico-chemical properties and metabolic activity of soil in poplar plantations replacing natural broad leaved forests. J Arid Environ 35:161–169

Joshi M, Bargali SS (1992) Certain microclimatic features under oak, conifer and mixed oak conifer canopies in parts of Kumaon Himalaya. Environ Ecol 10(4):874–877

Kasel S, Bennett LT (2007) Land-use history, forest conversion, and soil organic carbon in pine plantations and native forests of south eastern Australia. Geoderma 137:401–413

Manral V (2018) A comparative account of the microbial biomass carbon, nitrogen and phosphorus in soils of natural forests in Kumaon Himalaya. Ph. D. thesis, Kumaun University, Nainital, India

Medlicott HB (1864) On the geological structure and relations of the southern portion of the Himalayan Range between the rivers Ganges and Ravee. Memoirs of the Geological Survey of India (3rd ed) 41:1–26

Padalia K, Bargali SS, Bargali K, Khulbe K (2018) Microbial biomass carbon and nitrogen in relation to cropping systems in Central Himalaya, India. Curr Sci 115:1741–1750

Patel K, Kumar J, Kumar RN, Kumar B (2010) Seasonal and temporal variation in soil microbial biomass C, N and P in different types land uses of dry deciduous forest ecosystem of Udaipur, Rajasthan, Western India. Appl Ecol Environ Res 8:37–390

Qi Y, Chen T, Pu J, Yang F, Shulka MK, Chang Q (2018) Response of soil physical, chemical and microbial biomass properties to land use changes in fixed desertified land. Catena 160:339–344

Saxena AK, Singh JS (1984) Tree population structure of certain Himalayan forest associations and implications concerning their future composition. Vegetatio 58(2):61–69

Singh JS, Rawat YS, Chaturvedi OP (1984) Replacement of oak forest with pine in the Himalaya affects nitrogen cycle. Nature 311:54–56

Singh JS, Singh SP (1992) Forest of Himalaya: structure, functioning and impact of man. Gyanodaya Prakashan, Nainital, India

Singh RS, Srivastava SC, Raghuvanshi AS, Singh JS, Singh SP (1991) Microbial C, N and P in dry tropical savanna: Effects of burning and grazing. J Appl Ecol 28:869–878

Singh SP, Bisht K (1992) Nutrient utilization in Quercus leucotrichophora and Pinus roxburghii seedlings at five soil fertility levels. J Veg Sci 3(5):573–578

Singh SP, Pande K, Upadhyay VP, Singh JS (1990) Fungal communities associated with the decomposition of a common leaf litter (Quercus leucotrichophora A. Camus) along an elevational transect in Central Himalaya. Biol Fert Soils 9:245–251

Stevenson BA, Sarmah AK, Smernik R, Hunter DWF, Fraser S (2016) Soil carbon characterization and nutrient ratios across land uses on two contrasting soils: their relationships to microbial biomass and function. Soil Biol Biochem 97:50–62

Upadhyay VP, Singh JS (1989) Patterns of nutrient immobilization and release in decomposing forest litter in Central Himalaya, India. J Ecol 77:127–146

Usman S, Singh SP, Rawat YS, Bargali SS (2000) Fine root decomposition and nitrogen mineralization patterns in Quercus leucotrichophora and Pinus roxburghii forest in Central Himalaya. For Ecol Manage 131:191–199

Valdúa KS (1980) Geology of Kumaon Lesser Himalaya, vol. 66. Wadia Institute of Himalayan Geology, Dehra Dun, India, pp. 323–348

Wan KH, Huang QZ, He ZM, Yu ZP, Wang MH, Davis MR, Yang YS (2015) Soil C:N ratio is the major determinants of soil microbial community structure in sub tropical coniferous and broadleaf forest plantation. Plant Soil 387:103–116

Xu X, Thornton PE, Post WM (2013) A global analysis of soil microbial biomass carbon, nitrogen and phosphorous in terrestrial ecosystems. Global Ecol Biogeogr 22:737–749

Xu ZH, Ward S, Chen CR (2008) Soil carbon and nutrient pools, microbial properties and gross nitrogen transformations in adjacent natural forest and hoop pine plantations of subtropical Australia, J Soil Sediment 8:99–105

Yang K, Zhu J, Zhang M, Yan Q, Sun OJ (2010) Soil microbial biomass carbon and nitrogen in forest ecosystems of Northeast China: a comparison between natural secondary forest and larch plantation. J Plant Ecol 3(3):175–182

Publisher’s Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.