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Effect of altitude and aspect on soil organic carbon and nitrogen stocks in the Himalayan Mawer Forest Range

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ABSTRACT

The soil organic carbon (SOC) and nitrogen (N) stocks in mountainous forests are influenced by the forest diversity, topographic features, and climate change impacts. Role of forest SOC and N stocks in global C cycle has been a subject of great research recently, but the effect of topographic features on their dynamics at the stand level has received less attention especially under temperate conditions. In order to find out how topographic aspect and altitude affect SOC and N budgets, a study was conducted in the Himalayan Mawer Forest Range. We examined SOC and N stocks at two altitude zones (Z1: 1800–2200 masl & Z2: 2200–2500 masl) under North (N) and South (S) aspects at three soil depths (D1: 0–20 cm, D2: 20–40 cm and D3: 40–60 cm). The SOC stock was found to be decreasing with altitude from 105.9 Mg ha^{-1} to 78.3 Mg ha^{-1} under N aspect and from 81.6 Mg ha^{-1} to 74.0 Mg ha^{-1} under S aspect. SOC stock was higher by 16.5% under N aspect as compared to S aspect. The results lead to the conclusion that altitude has a negative effect on SOC stabilization and therefore altitude and aspect effect may be included in SOC stock estimation equations.

1. Introduction

Precise and accurate estimation of C and N stocks in forest soils is important for understanding the interactions of the biogeochemical cycle with global climate (Shaw et al., 2008). Globally a significant amount of C is stored in forests comprising nearly half of earth's terrestrial carbon (1146 Pg) including 764 Pg as soil C pool (Dixon et al., 1994; Goodale et al., 2002). Soil and biomass carbon storage is an essential attribute of stable forest ecosystems and a key link in the global carbon cycle (Bangroo et al., 2013; Davidson and Janssens, 2006). Because of this stability and storage role of SOC in terrestrial ecosystems, a slight change in its stock may influence global climate (Lal et al., 1998; Li et al., 2013; Uri, 2000).

Temperate forest ecosystem shows high spatial distribution of SOC both globally and regionally (Dar and Sundarapandian, 2013; Zhu et al., 2010). The great spatial variability on SOC and N stocks in mountainous regions are due to their varied environment, soil type-vegetation, and land use (Hoffmann et al., 2014). Forest diversity, and composition are in turn driven by topographic features (elevation, slope, and aspect) and climatic conditions (such as precipitation, temperature and radiation) (Griffiths et al., 2009; Lenka et al., 2013). The aggregate effect of these factors influences ecosystem restoration and soil carbon sequestration. The micro-climate, vegetation types, soil microbiology and altitude are effective predictors of C decomposition and accumulation rates (Matus et al., 2014). For example, soil N mineralization and nitrification rates of north-facing slopes are lower due to the cooler climate than south-facing slopes at each altitude (Zhang et al., 2012). In contrast, soils in warmer climate south-facing slopes have high mineralization, thus, lower organic matter content (Ping et al., 2015).

Thus, SOC storage potential under such ecosystem is primarily controlled by the variation in temperature, and soil moisture which vary with elevation gradients (Griffiths et al., 2009), aspect (Måren et al., 2015; Garcia et al., 2016) and slope (Perruchoud et al., 2000). SOC dynamics and sequestration are also influenced by interactions of chemical (clay) protection, and land use management strategies and practices (D'Angelo et al., 2009; Grandy and Robertson, 2007; Morris and Paul, 2003). While, the N stock variation with altitude are partly influenced by vegetation type and partly by altitude. Due to decrease in soil and air temperature with elevation (Vieira et al., 2011) a strong positive correlation of both organic carbon and nitrogen with the elevation is observed (Garcia et al., 2016).

SOC pool acts as a driving force to agro-ecosystem functions, regulating soil fertility, water-holding capacity and other soil quality parameters (Brevik, 2009) besides playing an important role in the global C cycle by way of mitigation of atmospheric levels of CO_2

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(Brevik, 2012). Thus, soil C and N pools are the key indicators of soil quality (Franzluebbers, 2002). Monitoring and improving C and N stocks to enhance soil quality and accentuate ecosystem services is crucial for sustaining environmental quality for future generations. In just a short time from the introduction of the term, scientists have rapidly moved to develop quantifiable indicators of soil quality (Franzluebbers, 2002).

In order to appraise forest soil quality, the most used indicators are SOC (Franzluebbers, 2002; Zornoza et al., 2007) total nitrogen (Amacher et al., 2007; Pang et al., 2006) followed by pH (Burger and Kelting, 1999; Zornoza et al., 2007) available nutrients (Pang et al., 2006; Zornoza et al., 2007, 2008), electrical conductivity (Zornoza et al., 2007, 2008), cation exchange capacity (Pang et al., 2006; Zornoza et al., 2007), C mineralization (Blecker et al., 2012; Jiménez-Esquilín et al., 2008), N mineralization (Leirós et al., 1999; Trasar-Cepeda et al., 1998) and enzyme activities (Chaer et al., 2009; Zornoza et al., 2007). Though scientists working across different forest ecosystems attempted to develop soil quality evaluation techniques, no consensus has been found with regard to soil characteristics that are considered to be of high quality (Duval et al., 2013; Zornoza et al., 2015). This is due to the dynamic interactions existing between various soils functions and difficulty in clearly separating them into chemical, physical and biological processes.

The stratification ratio (SR) i.e., degree of stratification of SOC and N pools with soil depth, could suggest soil quality/ecosystem working, as SOM being crucial to nutrient replenishment, soil erosion and water conservation (Franzluebbers, 2010). The soil stratification of physico-chemical properties is very common to both cropland and natural vegetation (Chang et al., 2012; Franzluebbers, 2002; Tfaily et al., 2014) and is defined as the ratio of a soil property of the surface layer to that as a sub-layer with soil depth depending upon the soil ecosystem. The degree of stratification can be used as an indicator of soil quality or soil ecosystem functioning because surface organic matter is essential to erosion control, water infiltration, and conservation of nutrients (Franzluebbers, 2002). A higher SR of SOC indicates enhanced soil quality (Ferreira et al., 2012). Although ample studies have reported the impact of vegetation type and topography slope on soil OC and soil N, relatively few studies have been conducted to examine the effect of topographic aspect and altitude on soil OC and soil N stocks and their stratification in relation to topographic aspect under natural vegetation and no such study has been yet conducted in the Himalayan Forests of Kashmir valley.

The objectives of this study were (1) to estimate the physico-chemical properties and soil OC and N stock, (2) to study the effect of altitude and aspect on soil capacity to store SOC and N and (3) assessment of soil quality by utilizing SR of SOC in the forest soils of Mawer Range of Langate Forest Division of Lesser Himalayas.

2. Methods and material

2.1. Site description

The study was carried out in the Mawer Range of Langate Forest Division located between 34° 17′ to 34° 22′ N and 73° 19′ to 74° 59′ E in Kupwara District of Jammu & Kashmir valley, India (Fig. 1). The mountain range is of lacustrine origin with well drainage system to the Mawar River. The slope varies from 15–30% to 30–50% with good fertility level as being deposits of Pleistocene and Post-Pleistocene in nature.

The forests of the Mawer division comprise predominantly of coniferous species extending throughout its length and breadth (Table 1). The principal coniferous species are Deodar (*Cedrus deodara*), Himalayan Pine (*Pinus wallichiana*) and Fir (*Abies pindrow*).

The distribution pattern of the principal species is influenced mainly by the factors such as altitude, aspect, rock, and soil. The Deodar and Himalayan Pine on lower belts occur both in mixtures and in pure stands. The Deodar covers about 44% of the total area of the commercial forest within altitudinal limits of 1650 to 2625 masl. Himalayan Pine constitutes about 19% of the stocked forest area of the division. It ranges from 1700 to 2300 masl along Deodar zone and extends up to 2900 masl in Fir zone. The Fir occupies higher altitudes of the division ranging from 2100 to 3500 masl. It constitutes about 37% of the total stocked forest area. The broad-leaved species are irregularly distributed throughout the division regardless of the altitudinal zonation. These are generally restricted to natural drains, moist depressions, and damp localities. The alpine zone is restricted above 3500 masl.

2.2. Experimental design and sampling

Two altitude zones Z1 and Z2 ranging from 1800 to 2200 masl and 2200–2500 masl, respectively, were studied for altitude and aspect effect on SOC and total N stocks in Mawer Forest Range of Langate Division along the N and S aspects.

Eight soil profiles with three laboratory replications were sampled at each altitude zone along the N and S aspects (8 soil profiles × 2 altitude zones × 2 aspects × 3 replications). Soil properties were studied at three different depths (D1: 0–20 cm; D2: 20–40 cm and D3: 40–60 cm). Uniform soil depths were used for a comparison between studied soils in order to avoid variation in results if sampling is done by genetic layers in the entire soil profile (Parras-Alcántara et al., 2015a) and was restricted to only 60 cm due to shallow bedrock in the majority of the cases.

2.3. Sample preparation and analyses

Soil samples were processed, air-dried and ground to pass through a 2-mm sieve. The remaining gravel content was also weighted. Soil bulk density (ρ_b) was measured by the core method (Blake and Hartge, 1986) using a 3 cm diameter and 10 cm deep core, particle size distribution by the International Pipette Method (Piper, 1966), soil pH was measured by glass electrode pH meter (Jackson, 1973). Nitrogen was determined by Kjeldahl method (Bremner, 1996) and OC by Walkley and Black method (Nelson and Sommers, 1982).

SOC stock and N stock were determined by following equations:

$$\mathrm{TSOCS} = \frac{\sum_{i=1}^{n} \mathrm{SOCC_i} x\ \rho_{bi} x\ d_i (1 - \partial_i)}{10} \tag{1}$$

$$\mathrm{TNS} = \frac{\sum_{i=1}^{n} \mathrm{TNC_i} x\ \rho_{bi} x\ d_i (1 - \partial_i)}{10} \tag{2}$$

where, TSOCS and TNS are the stocks of SOC and TN of all the soil sections considered (Mg ha^{-1}), respectively; i is the ith layer and n is the total no. of soil layers in a soil profile; $SOCC_i$ and TNC_i are the SOC and TN concentrations (g kg^{-1}) of the ith layer, respectively; ρ_{bi} and d_i are the bulk density (Mg m^{-3}) and the thickness (cm) of the ith soil layers, respectively; ∂_i is the proportion (%) of course (> 2 mm) fragments in the ith layer (IPCC, 2003).

The stratification ratio (SR) of SOC and N was calculated by dividing the concentration determined for each SOC and N pool in D1 layer by those in D2 layer and D3 layer (Franzluebbers, 2002).

The data were analysed for the analysis of variance (ANOVA) and differences were considered statistically significant for $p < 0.05$.

3. Results and discussion

3.1. Analytical results

The soils are loam and silty loam in texture. The pH ranged from 5.2 to 5.6 and 5.3 to 6.2 which in increases with the depth in Z1 and Z2, respectively. The soils were high in gravel content with mean 41.78% and 40.41% gravel content in Z1 and Z2, respectively (Table 2). The mean soil ρ_b in Z1 and Z2 varied from 1.42 and 1.30 Mg m^{-3} with an