Variation of Soil Organic Carbon at Glacier Foreland along Succession: a Case Study of Bhimtang Glacier Foreland, Manang, Central Nepal

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Abstract

Glacier forelands are considered as unique field laboratories where one can study succession pattern to ecosystem development. Glacier forelands are highly sensitive space to climate change. It forms space in a chronosequence order, i.e, younger moraine lies nearer to the glacier and older moraine lies farther from the glacier. There will be chronological patterns in biological colonization and nonbiological phenomenon. This present work is attempted to study the variation in soil organic carbon along the succession gradient at Bhimthang glacier foreland, Manang, Central Nepal. We hypothesized that younger moraine builds soil with less organic carbon than at older moraine. Five parallel transects, each representing a particular time period of formation were laid down. The distance of separation between each two transects was made 50 m. A total of 12 plots of 2 m × 2 m each laid at an interval of 30 m along each transect. Transects closer to the glacier terminus were regarded as younger moraine then away from it. About one kg of soil each below 10 cm from the top sampled from the center of each plot by the help of a soil corer. A total of sixty bags of soil samples collected during this study. The soil bulk density, soil organic carbon and altitude of each sample were measured. Soil bulk density found ranged between 0.53 to 1.83 mg/ml and soil organic carbon ranged between 0.73 to 1.18 percent. Present study supported the hypothesis of increasing soil organic carbon with increasing age of the glacier moraine. Accumulation of soil organic carbon may be supported by colonization of organisms and their death and decay.

Keywords: Bulk density, Chronosequence, Colonization, Glacier terminus, Moraine, Vegetation Cover

Introduction

Carbon on the Earth is a quantitative function of three reservoirs: Oceans, Atmosphere and Soil (Kempe, 1979). Each reservoir is in equilibrium within themselves and continuously exchanging and interacting with one other. Hiederer & Kochy, (2011) estimated 2469 Pg of organic soil carbon stored at the top one meter layer of soil globally. This amount of organic soil carbon is nearly three times greater than that of the above ground biomass and approximately two times greater than that of atmospheric carbon (Eswaran et al., 1993). Soil is called as the sink of organic carbon among all three reservoirs. Jenny (1941) explained that soil is a pioneer building block of ecosystem, a mixture of fragmented and partly or wholly weathered rocks and minerals, organic matter, water, air in varying proportions and differentiated into many horizons. It has a definite pattern of color, texture, nutrients and organic carbon in the earth. Formation of soil depends on time since exposure and topography (Darmody et al., 2005). Primary soil formation is clearly seen at glacier foreland. The pedogenic process in glacier foreland is a function of various variables such as temperature and moisture regimes (Hall et al., 1992). Study of soil formation process at glacier foreland gives various opportunities to understand ecosystem development to nutrients and organic carbon accumulation with time.

A glacier moraine is a good site to visualize natural chronosequence processes over time. The space formed after deglaciation can be understood via space-by-time substitutions process (Matthew, 1992). Distance of moraine away from glacier tongue is a proxy of age. Thus measurement of soil organic carbon at particular distance of moraine is a direct measure since formation. Chronosequence is a spatial sequence in which environmental factors other than time is considered to be unimportant either because they are invariant or because they are relatively ineffective (Matthew, 1992).

Soil closer to the glacier tongueis considered as younger and farther way is older (Huggett, 1998; Walker et al., 2010). This concept of chronosequence has been systematized by Jenny (1941) and utilized in the Norwegian glacier foreland succession study by Matthew (1992). Later, Huggett (1998) & Walker et al., (2010) and many other shave utilized this concept in each of their study.

Soil organic matter is an important component of the soil system. It is a good indicator of soil productivity. Soil property is characterized by their texture, organic matter, decomposition rate, soil cation exchange capacity, available phosphorus, nitrogen, pH (Stevenson, 1994). During the primary succession, not only the plants but also the soil undergoes remarkable changes such as soil accumulation, organic matter added by the vegetation, increase in water holding capacity, increase in soil aeration and soil porosity, decrease in bulk density, decrease in water runoff and other soil quality development (Singh et al., 2008). Knowledge on soil formation with organic carbon and nutrients accumulation have great potentiality to understand community to ecosystem development. This highly important aspect of plant ecology is less undertaken everywhere. Urgency of glacier foreland study is indispensable in the fragile landscape of Nepal in the face of global warming. Area of glacier foreland is rampantly increasing day to day in Nepal as well. Accessibilities to each of the glacier foreland would one of be constraining factors as all glacier forelands lie at high altitudes (above 3500 m asl). Another reason would be getting chronosequence of glacier foreland formation. Many glacier forelands in Nepal have mixed topographies that confused chronosequence. Thus this study has been initiated at the Bhimthang glacier foreland, Manang, Central Nepal. The glacier foreland formed by Bhimthang glacier has a clear chronosequence of distance. Distance of retreated glacier foreland away from glacier tongue was considered as equivalent to time. The main objective of this study was to discern the pattern of the soil bulk density and soil organic carbon along the Bhimthang glacier foreland, Manang, central Nepal with the hypothesis of increasing pattern of soil organic carbon with increasing distance from the glacier.

Materials and Methods

Study site

This study was carried out in Bhimthang glacier foreland (Figure 1). Bhimthang lies in lower Manang, Central Nepal with the coordinates ranging between 28°27' to 28°46.35' N latitude and 84°10.44' to 84°30' E longitude (Figure 1: a, b & c).

Figure 1: Glimpse of the study site Photo: C.B. Baniya, 2019

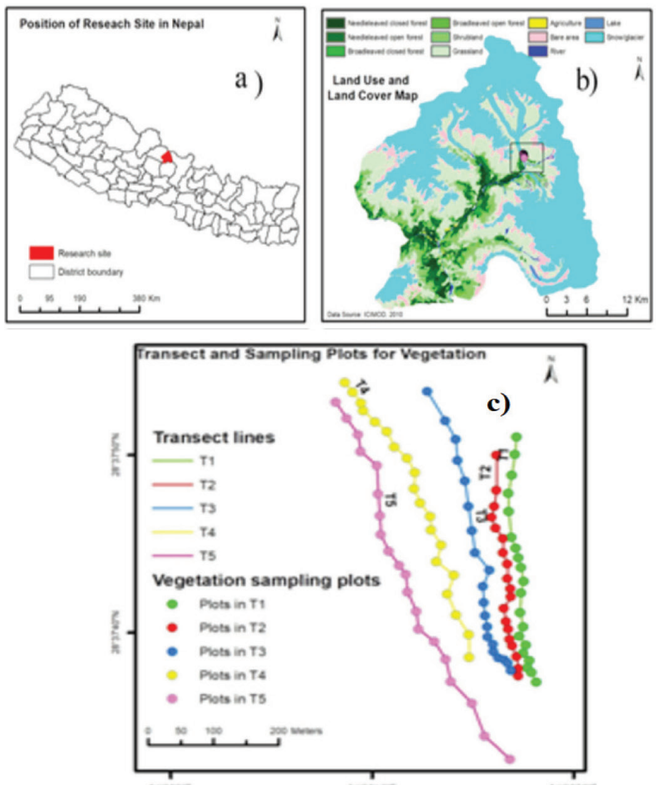

Figure 2: Map of the study area (Bhimthang) (a) Location of Manang district in the map of Nepal (b) Land use and landcover of Manang district and (c) Studied sample plots along each Transect (T1, T2, T3, T4 and T5).

The study area was characterized by high altitude (above 3500 m asl), cold climate, and semi-desert environment with snow fall in winter.

Manang is a unique district in Nepal. Part of this district facing south of the Annapurna range is lower Manang. Bhimthang falls under this class. Part of Manang district facing north of the Annapurna range is upper Manang. Monsoon wind passes through lower Manang to upper Manang after diminishing intensity drastically by the Annapurna range. Moisture decreases from south-east to north-west.South-facing slopes are signiûcantly drier and warmer than north facing slope towards upper Manang. Dense vegetation can be seen in northernslopes of upper Manang and southern slope in lower Manang. Soil moisture is one of determining factors in this phenomenon.

Climate

Meteorological data of Jomsom station nearly at similar altitude of Bhimthang study site was used. Thirty years (1987-2018) climatic data (temperature and precipitation) for Jomsom station was taken from Department of Hydrology and Meteorology, Government of Nepal. According to this record, the average temperature found ranged between -0.78 to 13.39°C during winter and 12.13 to 24.41°C during summer (Figure 3). The mean annual rainfall for the study area was 972.08 mm with the highest monthly rainfall in July (1622.4 mm) and the lowest in November (138.5 mm). November to February was dry months although occasional rainfall occurred throughout the year. These weather conditions have typically been supporting the sub-alpine to alpine vegetation in and around Bhimthang area.

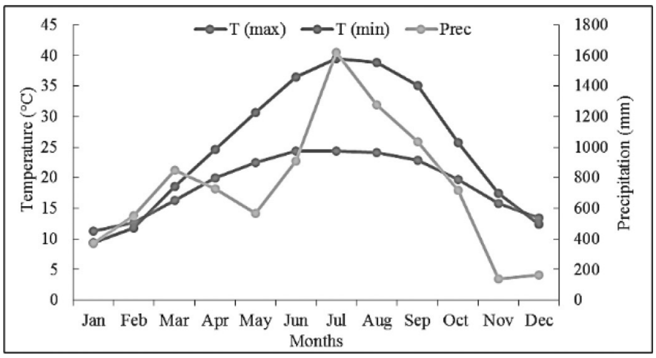

Figure 3: Ombrothermic graph representing the monthly mean maximum and minimum temperature and precipitation trend of Bhimthang, Manang district (Jomsom as meteorological reference point 1987- 2018) (Data Source: Department of Hydrology and Meteorology, Government of Nepal).

Phytogeography and vegetation

The study site is situated inthe lower Manang. Bhimthang is a part of Gyasumdo or lower Manang valley, is a glacially formed U-shaped valley traversed by the Dudhkhola and surrounded by high mountains. It is situated between 3600 m to 3750 m above sea level to wards north-eastern part between Annapurna Conservation Area (ACA) and Manaslu Conservation Area (MCA), Central Nepal.

Vegetation around the studied area are sub-alpine to alpine type. The dominant tree species were *Abies spectabilis* (D.Don) Mirb., *Taxus wallichiana* Zucc., *Tsuga dumosa* (D.Don) Eichler and *Pinus wallichiana* A.B. Jacks. with scattered trees of *Betula utilis* D.Don and *Acer pectinatum* Wall. ex Paxwith patches of *Juniperus* and *Rhododendron* bushes under the open canopy. The dominant shrubby vegetation patches of *Rhododendron lepidotum* Wall. ex G. Don, *Cotoneaster microphyllus* Diels, *Lonicera spinosa* (Decne.) Jacq. ex Walp., *Salix lindleyana* Wall. ex Andersson, *Gaultheria tricophylla* Urb.and *Potentilla fruticosa* Auct.etc were found towards southern slopes.

Data collection

The sampling was done in the south-western aspect of lateral moraine of Bhimthang glacier during June of 2019 and 2020. The moraine was found colonized dominantly by shrub as well as some posts of tree species. Five parallel transects (T1, T2, T3, T4 and T5), each representing a particular time of retreat were laid on the lateral foreland moraine. Each transect located at certain distance away from the glacier tongue, represented a definite time of retreat. The distance between each two transects was made 50 m each. Along each transect, a total of 12 plots of 2 m × 2 m each were laid down at an interval of 30 m each. A total of 60 plots sampled for this study. About one kg of soil sampled from the center each plot. Soil sampled with the help of a soil corer each below 10 depths from the top. Sampled soil collected into a zipper plastic bag with a proper labeling inside it so that will not mix up with other samples. All samples dried first and sieved properly after brought in the laboratory before further analysis. All analysis was performed in the Ecology Laboratory, Central Department of Botany.

Soil Bulk density

Soil Bulk density was determined after following the laboratory procedure given by Gupta (2002).

Soil organic carbon (SOC)

Soil organic carbon was determined by using Walkley-Black Methodgiven by Gupta (2002).

SOC was calculated using following formula:

$$\text{Soil Orgainc Carbon (SOC)} = \frac{\text{N(B − S) x 0.003 x 100}}{\text{Mass of dry soil (gm)}}$$

Where, N = Normality of ferrous ammonium sulphate (0.5N).

B = Volume of ferrous ammonium sulphate for blank titration (ml).

S = Volume of ferrous ammonium sulphate for sample titration i.e. soil (ml).

Data analysis

Data entered first in the spreadsheet which later imported into R (R Core Team, 2020) and analyzed. Descriptive analysis performed first in the plot-wise data but later utilized to transect-wise data to remove spatial autocorrelation. Each transect was taken as equal status, dummy variable. As position of each transect T1 was the youngest moraine and T5 was the oldest one. Pearson's correlations and simple linear regression were performed after visualizing patterns in pairs plot. Graphics were drawn through R and Map was drawn through QGIS.

Results and Discussion

Descriptive analysis among variables

Transect, altitude, soil organic carbon (SOC) and Bulk density were variables plotted in pairs plot (Figure 4) showed interesting pattern among each other. Transects showed declining pattern with altitude (Figure 4). It meant that younger transects were at the higher altitude and older transects were towards the lower altitudes. This study design justified spatio-temporal design for glacier foreland studies done in Europe such as Matthew, (1992); Huggett, (1998); Walker et al., (2010). Likewise, inclining pattern was observed in between transect and soil organic carbon. All these variables indicated patterns along transect and altitudes.

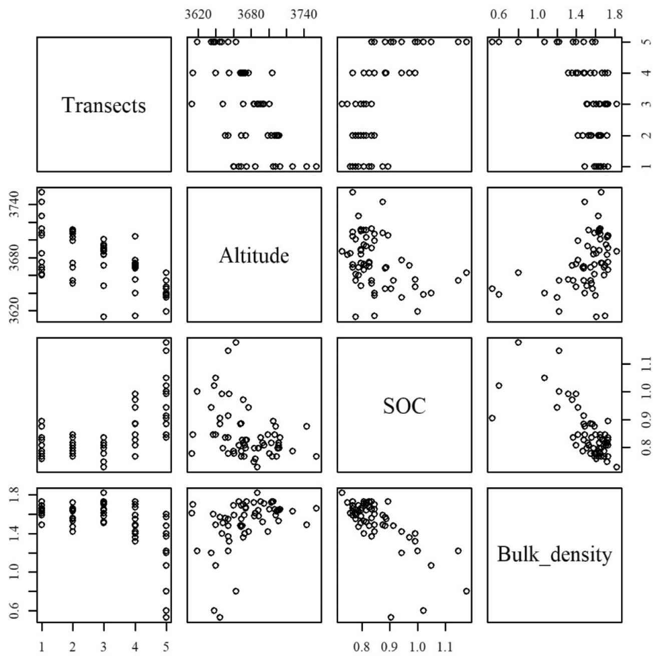

Figure 4: Pairs plot among studied variables along Bhimthang glacier foreland

Correlations among variables

Altitude showed statistically significant negative correlation with soil organic carbon($r = -0.38$, $p < 0.05$) but statistically significant positive correlation with soil bulk density ($r = 0.41$, $p < 0.001$, Figure 5). This study found statistically strong negative relationship between soil bulk density and soil organic carbon ($r = -0.72$, $p < 0.001$, Figure 5).

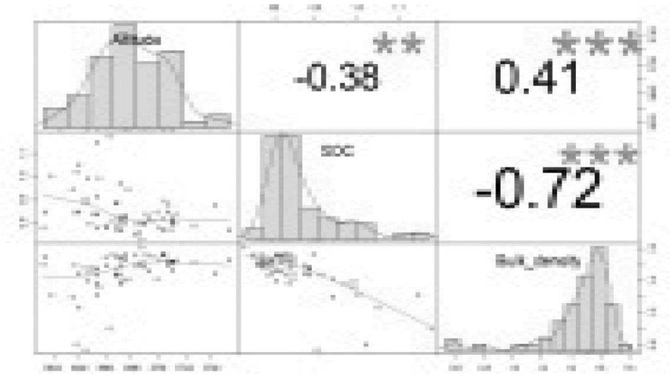

Figure 5: Pearson's correlation coefficient among variables measured during study

Change in soil organic carbon with altitude

Soil organic carbon found a significant linear declining pattern with altitude ($p = 0.02$, $R^2 = 0.15$, Figure 6). This regression coefficient of this model was 0.15. This finding is well supported the conventional and general finding of high content of soil organic carbon found in the old moraine. As moraines are getting older that get longer time to accumulate humus content in soil hence having high amount of soil organic carbon in moraines at lower altitudes. Findings of Elmer et al. (2012), Shakya & Baniya (2019) and Gurung (2012) also supported.

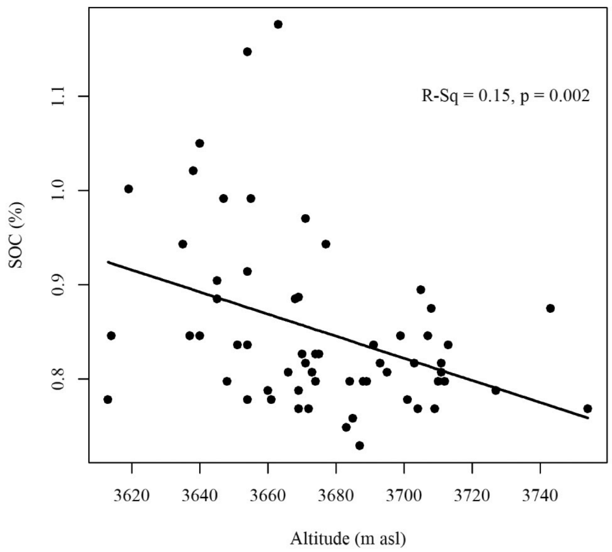

Figure 6: Relationship between soil organic carbon (%) and altitude (m asl). The fitted line is statistically significant first order linear regression model.

Change in soil organic carbon with soil bulk density

The soil organic carbon showed statistically strongly significant declining pattern ($p < 2e-16$, $R^2 = 0.52$) with soil bulk density (Figure 7). Soil bulk density depends on the compaction, consolidation and organic carbon content in the soil (Morisada et al., 2004). Glacier foreland is a place of harsh environmental condition. No plant propagules were found in the recently deglaciated forelands. Hence very less organic matter will be expected than in older moraine. Decomposition proceeded faster at more developed sites situated at lower altitudes in the glacier foreland (Espersch¨utz et al., 2011).

High altitude range land of Nepal showed relatively higher content of soil organic carbon than lower elevation (Limbu et al., 2013). Probable reason behind of such findings would be low soil temperature and less decomposition. If we applied this interpretation into our glacier foreland, we would expect more soil organic carbon towards younger moraine than at older moraine. To obtain high amount of soil organic content certainly there must have vegetation and their decomposition. But in case of primary succession, the recently deglaciated soil did not get enough time to colonize by living organisms hence very less accumulation of organic matter. Thus, formation time of soil organic matter is crucial. Glacier foreland studies such as Burga et al. (2010), Wietrzyk-Pelka et al. (2020) have found similar pattern of soil organic matter in the glacier foreland. Soil bulk density has almost similar pattern as expected that is negative correlation with soil organic matter. However, Shakya and Baniya, (2019) found no significant relation between soil bulk density and soil organic carbon in the glacier foreland study nearby Bhimthang area. Discrepancy between results would be time since deglaciation. Though these two glaciers lie in the same district but lie completely different topography. Hence our all findings supported the hypothesis of increasing soil organic matter with succession time.

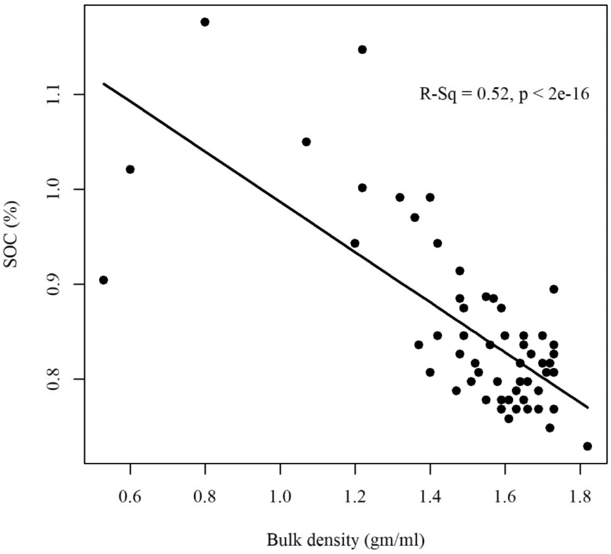

Figure 7: Relationship between soil organic carbon (%) and soil bulk density (gm/l). The fitted line is statistically significant first order linear regression model with R^2-value 0.52 and $p < 2e-16$.

Conclusion

This study concluded that younger glacier moraine lies closer to the glacier terminus, characterized by lesser amount of soil organic matter contents but higher soil bulk density. Similarly, soil organic matter increased linearly with increasing age of soil formation. Formation of soil may be facilitated by time and stochastic factors such as environmental variables.

Author Contributions

The first author did field work, collected data, analyzed data and wrote manuscript.

The last corresponding author designed method, assisted field study, assisted data collection, data analysis and helped to write and revise manuscript.

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