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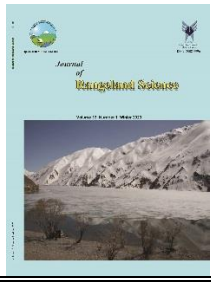

Research and Full Length Article:

Plant Species Diversity and Phytomass along an Altitudinal Gradient of Himalayan Rangeland of Eastern Nepal

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Abstract. The most important environmental driver is the elevation in mountain ecosystems. It strongly influences the distribution of species richness. Species richness is an indicator of the biological diversity and ecological condition of the area. Study was conducted in Milke-Jaljale Mountain ridge, in 2013. Objective of the study are to understand the status of phytomass, species diversity, and physico-chemical properties of soil along the altitudinal gradient; to know the correlation between plant species and environmental factors. We used a transect line method to enumerate the plant community in each sampling plot. Phytomass was estimated by the total harvesting method. Soil properties were determined with standard procedures. SPSS and R software were used for data analysis. Plant diversity indices, viz., Shannon-Wiener diversity index, Simpson's dominant index, Pielou's index, and Margalef index, were highest at the low altitude and the lowest value at high altitude. Above Ground Biomass (AGB), Below Ground Biomass (BGB), Soil Organic Carbon (SOC) and Soil Total Nitrogen (STN) were most elevated in high altitudes. Phytosociological indices and environmental factors except soil moisture and SBD, were high at high elevation. First axis of ordination was positively correlated with SBD, moisture, ABG, and BGB and negatively with STN. The low-altitude rangelands had high anthropogenic activities; grazing, trampling and burning disturbed the natural storage of organic carbon, nitrogen, phytomass, and diversity. The study showed a linear negative relationship between phytomass and altitude.

Key words: Elevation, Physicochemical, Interrelationship, Ordination, Hump-shaped

Introduction

High altitude Himalayan rangelands are home to a unique assemblage of flora and fauna (Yonzon and Heinen 1997). It covers about 2 million sq. km. (60% of Hindu Kush-Himalayan Region). This unique type of mountain ecosystem supports a large livestock industry, accommodates essential watershed functions, and provides valuable and biologically diverse resources. In such mountain ecosystems, the most critical environmental driver is the elevation (Zimmerman *et al.* 1999; Lomolino, 2001; McCain and Grytnes 2010; Neri *et al.* 2016). This variable influences temperatures that determine the diversity, structure of plant communities, and soil properties along altitudinal gradients in the mountains with high altitude grasslands (Safford 1999).

Species richness is an indicator of biological diversity (Peet 1974) and the ecological condition of the area. Variation in species richness can be linked to several environmental gradients (Palmer 1992; Huston and DeAngelis 1994). Changes in temperature, moisture, topography, aspect, and soil type along elevation gradients are considered critical drivers of spatial variation in plant species richness (Wallace 1878; Lomolino, 2001; Pausas and Austin 2001; Malik and Malik 2012), evenness (Hegazy *et al.* 2007), and species composition (Semenova and van der Maarel 2000).

Several reports have mentioned a decreasing trend in species richness with increasing elevation (Gentry 1988; Stevens 1992; Patterson *et al.* 1998; Heaney 2001; McCain 2007).Whereas others have mentioned a hump-shaped relationship between species richness and elevation (Lieberman *et al.* 1996; Odland and Birks 1999; Grytnes and Vetaas 2002; Bhattarai *et al*. 2004; Paudel *et al.* 2018). The low elevation sites are relatively densely populated because human interference in these areas facilitates the introduction and establishment of non-native species (Rawal and Pangtey 1994).

Phytomass is a primary component of the global carbon cycle (Olff *et al.* 2002). Precipitation is the main determinant of phytomass production (Stegen *et al.* 2011; Metcalfe *et al.* 2014), whereas disturbances alter the phytomass distribution (Zhou *et al.* 2006). Namgail *et al.* (2012) stated that the pattern of phytomass is poorly known than the pattern of phytodiversity along an altitudinal gradient. Changes in plant species diversity affect several ecosystem processes, viz., primary productivity (phytomass), and vegetation dynamics (Naeem *et al.* 1996; Hector *et al.* 1999; Loreau *et al.* 2001).

The effects of phytomass on species diversity and the effects of diversity on ecosystem productivity (phytomass) are closely related but controversial issues in ecological research (Schwartz *et al*. 2000; Aarssen 2001; Grime 2002; Stevens 2006; Guo 2007; Grace *et al.* 2007). The species diversity-phytomass relationship can be positive (Shuaifeng *et al.* 2018), negative (Rastetter *et al.* 2004; Namgail *et al.* 2012), unimodal (also called hump-shaped) (Bhattarai *et al.* 2004; Paudel *et al.* 2018), and U-shaped or no relationship (Brown and Gibson 1983; Currie 1991; Mittelbach *et al.* 2001; Gillman and Wright 2006; Bai *et al.* 2007; Pärtel *et al.* 2007).

Grazing intensity is an essential form of disturbance (Grime 2006) on species richness and phytomass, particularly in grassland systems (Milchunas *et al.* 1988). Grazing, directly and indirectly, affects plant communities (Hay and Kicklighter 2001), changing the ecology of different species (Olff *et al.* 2002; Facelli and Springbett 2009). However, the magnitude of grazing effects depends on ecosystem properties and the evolutionary grazing history (Milchunas *et al.* 1988).

Phytomass influences physicochemical characteristics of soil (Johnston 1986). Physico-chemical characteristics of

grassland soils vary in space and time. The physical properties of soil are generally influenced by vegetation and species diversity (Sharma *et al.* 2010). Shrestha(2016), Saeed *et al.*(2015), Debnath *et al.*(2012), Xu *et al.*(2018), Kumar *et al.*(2010), Garhwal *et al.* (2013) and Sigdel *et al.*(2015) studied the Physicochemical character of rangeland soil in the Himalayan region.

Some scholars studied the phytomass in Himalayan rangelands. Their studies are upper Mustang (Maharjan 2010), Manang, Nepal (Bhattarai *et al.* 2004), central Himalayan grassland, India (Ram *et al.* 1989), and Alpine steppe and alpine meadow of the Tibetan plateau (Yang *et al.* 2009; Liu *et al.* 2017).

The objectives of the study were: (i) to understand phytomass, species diversity, and physico-chemical properties of soil along an altitudinal gradient and, (ii) to understand the influence of altitudinal gradient on interrelation among phytomass, species diversity and physicochemical properties of soil.

Materials and Methods

Study areas

The research work was conducted in the Milke-Jaljale Mountain ridge, political border of the three districts, viz., Taplejung, Tehrathum, and Sankhuwasabha, (27°09'30.5"N to 27°22'15"N and 87°26'09"E to 87°34'14"E) of eastern Nepal (Fig. 1) on September 2013. The altitude of the study site ranges from 3000 to 4500 m asl.

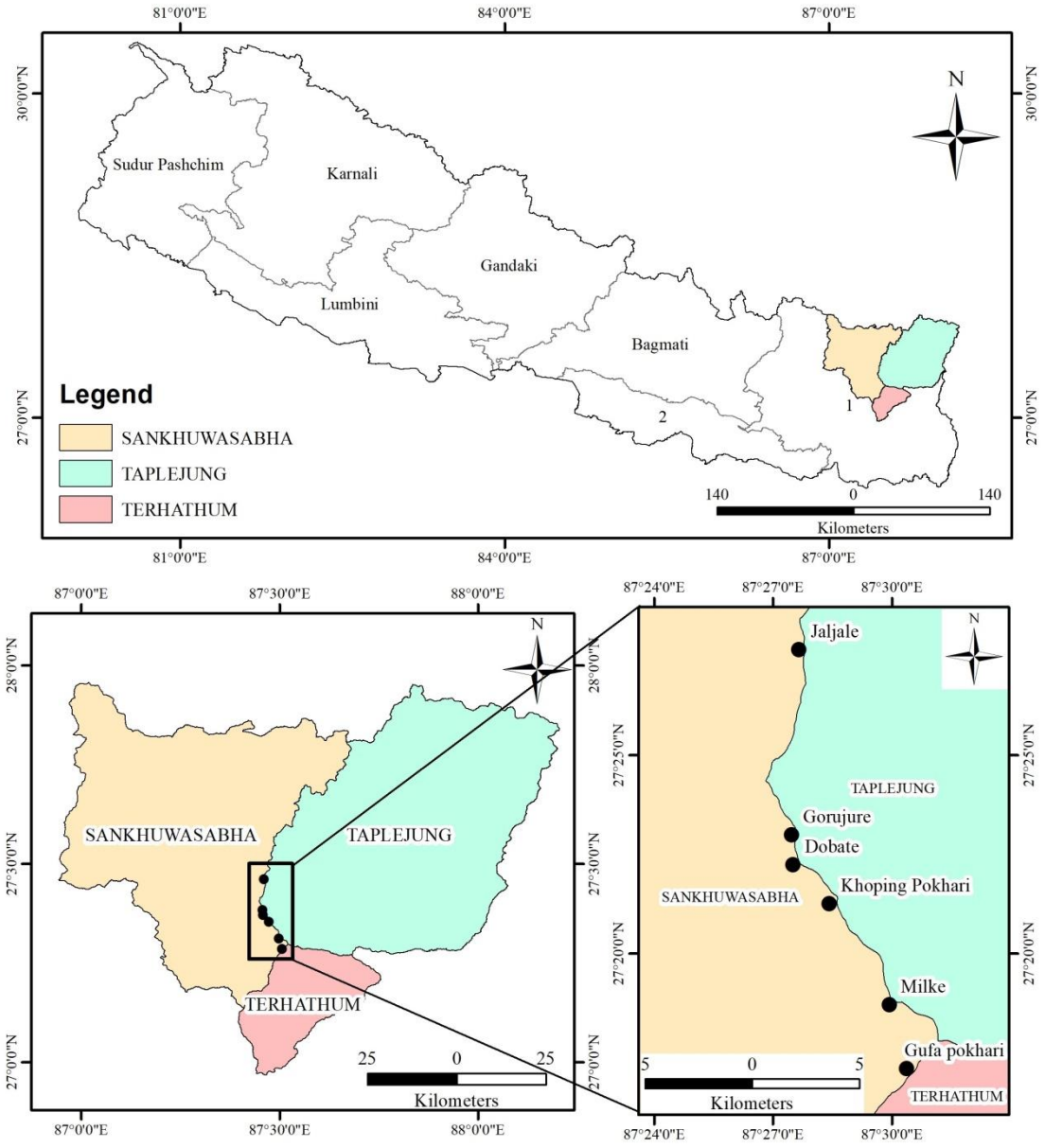


Fig. 1. Location map of study sites, Milke-Jaljale-Gupha area, Eastern Nepal (Map by C. Silwal)

The climate of the study area is moist temperate type, which receives moderate snowfall from December to February. The average climatic detail (2011-2013) of the study area is given in Fig. 2. Mean annual maximum temperature was 23.6±4.95°C, whereas mean annual minimum temperature was 4.12±5.24°C. Mean annual rainfall was 2,274 mm.

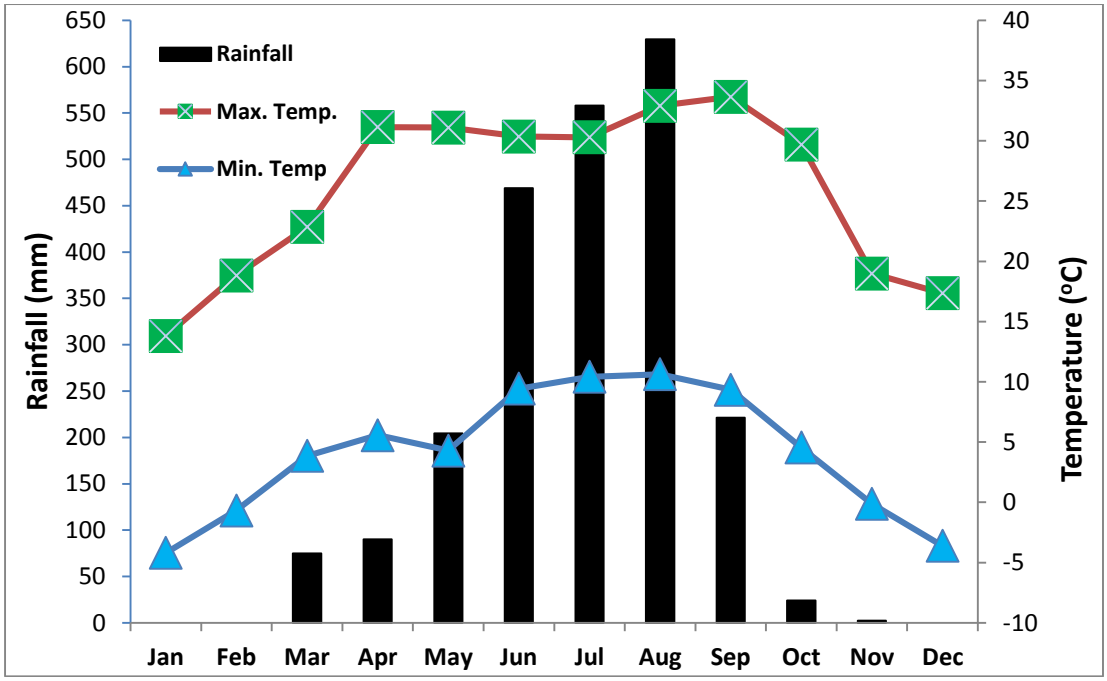


Fig. 2. Climatic detail of the study area (2011-2013) Source: Field study, 2013

The area is livestock grazing (yak, sheep, cows, and buffaloes) with the dominant vegetation of *Agrotis micrantha*, *Agrotis pilosula*, and *Carex* sp. Tree-line lies at 3800 m asl in the study area. The study area has two distinct regions, i.e., cold, harsh climate and rocky mountain, which is above 3500 m asl and accessible and moderate climate below 3500 m asl. Usually, buffaloes and cows graze in the lower belt in the summer season; in the meantime, yaks and sheep are taken to Rocky Mountains, upper region. This ridge serves as a habitat corridor between Makalu-Barun Conservation Area, and Kanchenjunga Conservation Area, Nepal. Both the conservation areas touch the Qomolongma Biosphere Reserve, Tibet (Koirala 2002).

Research Design

After the reconnaissance survey, the research work was carried out at three different altitudinal sites, 3,000 m asl (Milke), 3,500 m asl (Gorujure), and 4,000 m asl (Jaljale) in September and October 2013. We used a transect line method to enumerate the plant community in each sampling plot. We randomly selected a point to begin vegetation sampling (without any prior knowledge of plant community at that point) and marked it. We established a 40 m transect from the central sampling point and placed 900 cm^2 (30 × 30 cm) quadrats at every 10 m intervals along this transect. A total of 45 sample quadrats, 15 quadrats from each altitudinal site, were sampled at the study sites.

The same quadrat was used for soil samples after completing the plant community analysis. Soil samples were collected from each quadrat of soil core having 4 cm diameter and 15 cm length. Soil core was separated into three sections, viz., 0–5 cm (first soil profile), 5-10 cm (second soil profile), and 10–15 cm (third soil profile) slice with 5 cm strata of each slice. Each slice of the soil was packed in a separate zipped polythene bag and brought to the laboratory for analysis. The soil sample was dried in an oven at 100°C until constant weight. It was crumbled with thumbs and sieved through a 2 mm sieve. Meanwhile, the bulk density nof the soil sample was also determined. The remaining particles were weighed, sieved, and preserved for further analyses.

Another 900 cm2 (30 × 30 cm) quadrat was laid down near to (around 30 cm far)

each sampled quadrat of plant communities to obtain the phytomass samples. For phytomass estimation (above-ground phytomass), entire plants of the sampled quadrate were cut at ground level, packed separately in nylon bags, and sun-dried. Similarly, to estimate the below-ground phytomass, 15 cm deep of the quadrat was excavated for plant roots collection. The excavated soil was washed with a water jet in a 2 mm sieve. Washed plant roots were transferred to a spread plastic, and impurities like sand and stones were removed. The sun-dried phytomass was oven-dried at 70°C for 48 hours till constant weight was attained.

Sample analysis

a) Phytosociology analysis

The Shannon-Wiener Diversity Index, (H) was calculated using the following equation:

$H = \sum Pi(\ln Pi)$, (Shannon and Wiener, 1949)

Where:

Pi is the proportion of each species in the sample.

The Shannon-Wiener index values (H) can range from 0 to ~ 4.6 using the natural log (ln).

Simpson's index (D) was calculated with the following equation:

$D = \sum_{i=1}^{s} n(n-1)/N(N-1)$, (Simpson, 1949)

Where:

n - No. of individuals in the ith species.

N – Total no. of individuals for all species.

The Simpson's Index (D) can range from 0 to 1. Lower the values higher the diversity.

Pielous species evenness index (E) was calculated as

$E=H/\ln S$ (Pielou, 1969)

Where:

H - Shannon-Wiener index,

S – Total number of species in the sample, and

ln– Natural logarithm.

The Margalef species richness index (d) can easily be calculated as:

$d = (S - 1) / \ln N$ (Margalef, 1958)

Where:

S- number of species,

N - total number of individuals in the sample, and

ln– natural logarithm.

b) Determination of soil moisture

Moisture content in soil was determined by using the formula.

$$\%\ \text{soil moisture content} = \frac{\text{weight of moist soil} - \text{weight of dry soil}}{\text{weight of dry soil}} \times 100$$

c) Determination of soil bulk density

The bulk density of sampled soil was determined by the standard method. Equation (C1) was used for the calculation of soil bulk density.

$$\text{Bulk Density}\left(\text{g/cm}^3\right) = \frac{\text{Oven Dry Mass } (g)}{\text{Core Volume } (\text{cm}^3) - \left[\frac{\text{Mass of coarse fragments (g)}}{\text{Density of Rock fragments } (\text{g/cm}^3)}\right]} \quad \text{.....(C1)}$$

Determination of total organic carbon

Soil organic carbon was analyzed from the stored sample by (Walkley and Black 1934).Chromic Acid Wet Oxidation Method. The organic carbon (%) and total organic carbon were calculated using equations (C2) and (C3) respectively.

$$\text{Organic Carbon} = \frac{0.003 \times N \times 10\ \text{ml}\ (1 - T/S)}{ODW} - \frac{3(1 - T/S)}{W} \quad \text{(C2)}$$

Where:
N = normality of $K_2Cr_2O_7$
T = volume of $FeSO_4$ used in the sample titration (ml)
S = volume of $FeSO_4$ used in the blank titration (ml)
ODW = oven-dry weight (g) of soil sample

$$\text{Soil Organic Carbon (SOC)} = \text{organic carbon content (\%) of soil} \times \text{soil bulk density (g/cm}^3) \times \text{thickness of horizon (cm)} \quad \text{(C3)}$$

Determination of total nitrogen

The nitrogen content in the soil sample was determined by the Kjeldahl method (Pansu and Gautheyrou 2006). The nitrogen % and total nitrogen were determined using the relation N1 and N2 respectively:

$$\text{Nitrogen (\% wet basis)} = \frac{\text{Sample titer - Blank titer)} \times \text{N of HCl} \times 14 \times 100 \times 100}{\text{Aliquot (ml)} \times \text{Wt. of sample (g)} \times 1000} \quad \text{(N1)}$$

$$\text{Total Nitrogen (TN)} = \text{Organic Nitrogen content (\%) of soil} \times \text{soil bulk density (g/cm}^3) \times \text{Thickness of horizon (cm)} \quad \text{(N2)}$$

Statistical Analysis

Values of diversity index, viz., Shannon-Wiener index, Simpson's Index, Pielou's index, Margalef index, phytomass, and physicochemical value of soil were square-root-transformed before statistical analysis to ensure homogeneity of variance. The transformed values were analyzed using a one-way analysis of variance (ANOVA). Differences in community characteristics and soil properties between different sites were compared using, Tukey HSD, multiple comparisons ($P < 0.05$) following ANOVA procedures (IBM, 2011).

Ordination techniques reveal correlations between the spatial distribution of plant communities and environmental factors, which might have crucial ecological significance (Appelgren and Mattila, 2005). R Programming was used in the Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA) analysis to investigate the relationships between vegetation distribution and environmental factors. The nature of connections is shown in the ordination diagram by vectors with lengths proportional to their importance and directions showing their correlations with each axis.

Pearson's product-moment correlation coefficient was used to express the significance of a linear relationship between multiple parameters. A Monte Carlo permutation test was performed to determine the accuracy of the relationship between the two data sets (Peres-Neto *et al.* 2006).

Results

a) Species Diversity and Richness

The plant community and diversity showed the presence of 11 families comprising 20 genera in the three study sites. Agrostis micrantha (111.9) had the highest Importance Value Index (IVI), Poa sp. (94.4) followed the second position, and Bistorta macrophylla (9.56) had the least value in Jaljale site at 4000 m asl. Similarly, Carex sp. (81.38) had the highest IVI, Fimbristylis aestivalis (Retz.) Vahl (51.84) followed the second position, and Cynodon doctylon (L.) Pers. (3.89) had the least value in 3500 m site at 3500 m asl; Helictotrichon asperum (Munro) Bor (50.05) had the highest IVI, and Galium sp. (42.09) followed the second

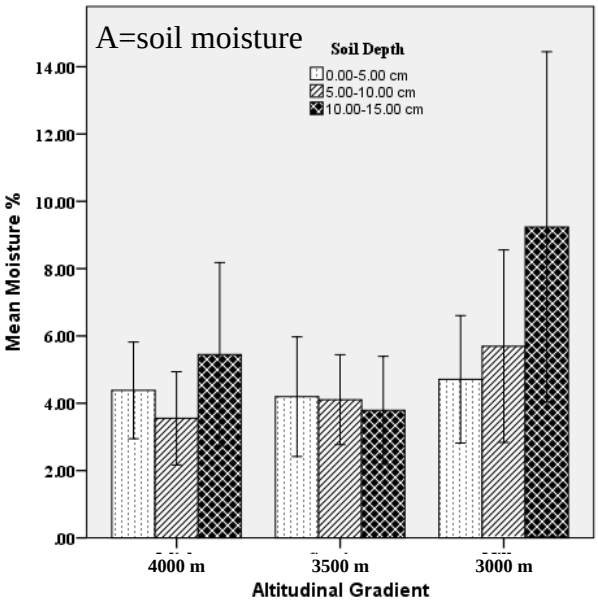
position and Poa annua (3.89) had the least value in Milke site at 3000 m asl (Table 1). The evenness of plant community diversity was high in 4000 m asl.

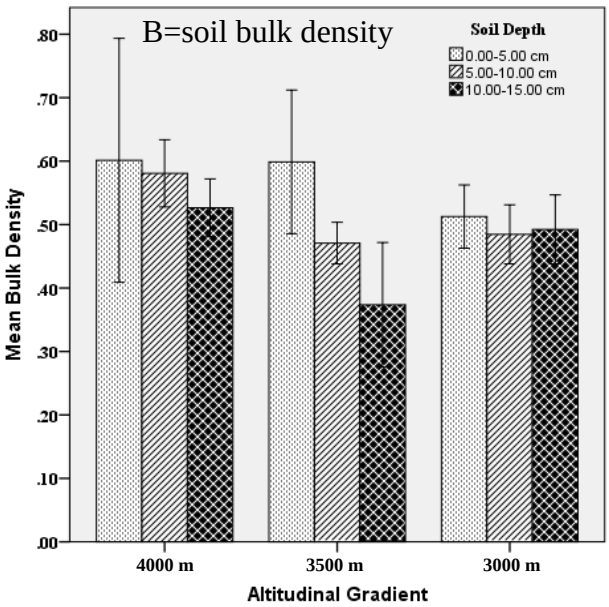
All diversity indices, viz., Shannon-Wiener diversity index, Simpson's dominant index, Pielou's index, and Margalef index, were highest at the low altitude (3000 m) and the lowest value at high altitude (4000 m) (Table 1). Shannon-Wiener diversity index was significantly different ($p<0.05$) when comparing between 3000 m (1.58±0.22) to 3500 m (1±0.32) and 3000 m (1.58±0.22) to 4000 m (1.008±0.24). Similarly, the Simpson index was significantly different ($p < 0.05$) when comparing between 3000 m (0.76±0.04) to 3500 m (0.56±0.13) and 3000 m (0.76±0.04) to 4000 m (0.56±0.09). Pielou's index was not significantly different in all three study sites. Margalef index was significantly different ($p<0.05$) when comparing 4000 m (4.08±3.9) to 3500 m (0.7±0.32).

The study revealed that dicot plants were distributed densely at low altitudes but sparsely at high altitudes. The reverse was the case for monocot plants (Table 1).

Both Above Ground Phytomass (AGB) and Below Ground Phytomass (BGB) depicted large spatial variations (Table1).

The range of the AGB was from 0.35 t/ha to 1.50 t/ha; similarly, BGB was from 16.93 t/ha to 43.48 t/ha. The study showed that ABG and BGB of 4000 m (1.02±0.32 t/ha and 41.62±2.07t/ha respectively) were significantly higher than that of 3000 m (0.62±0.24t/ha and 22.04±5.9t/ha) and 3500 m (0.62±0.16t/ha and 29.17±8.6t/ha).The value of 3500 m and 3000 m was not significantly different. The study result showed that both AGB and BGB of study sites exhibited an increasing trend with altitudinal rise.





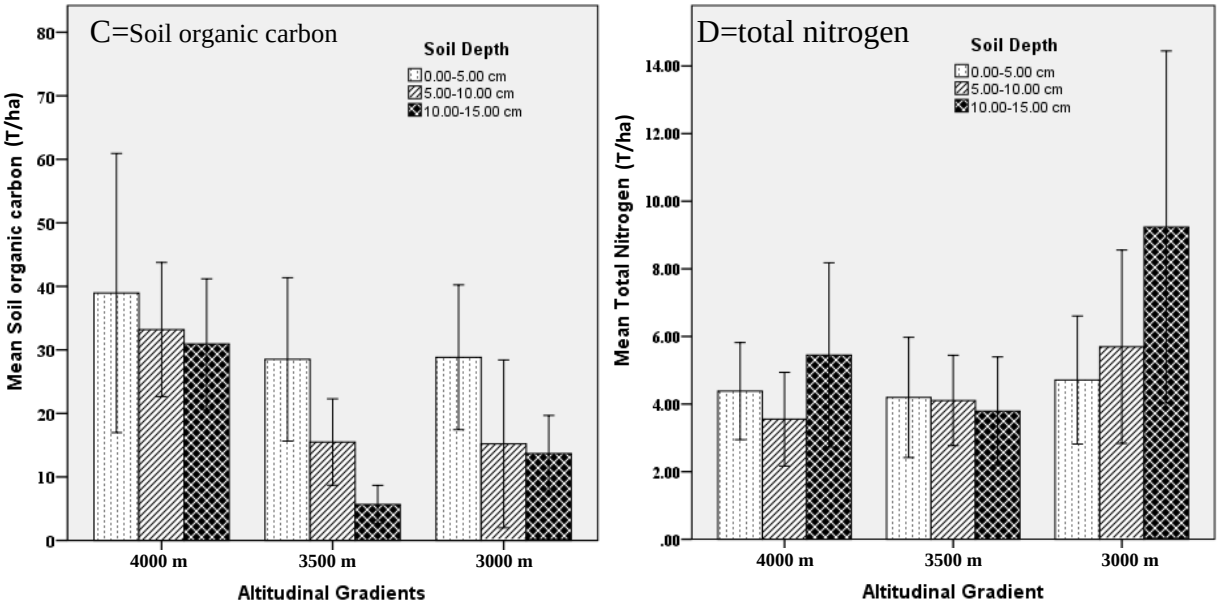


Fig. 3. Means± standard errors Interaction effects of soil depth by altitude, A) Effects of different soil depth on moisture, B) effects of different soil depth on soil bulk density, C) effects of different soil depth on SOC and D) effects of different soil depth on total nitrogen

b) Soil moisture, Bulk density, Carbon and Nitrogen status

The study revealed that moisture percentage was the highest in 3000 m asl (Milke) (6.55±4.24). 3500 m asl (Gorujre) (4.04±1.65) and 4000 m asl (Jaljale) (4.47±2.18) had more or less equal moisture (Table 1, Fig. 3 (A)). The moisture was significantly different from 3500 m and 3000 m ($p<0.05$). The moisture of 0-5 cm and 10-15 cm of 3000 m and 10-15 cm of 3000 m, 3500 m, and 4000 m were significantly different.

The soil bulk density was the highest in 4000 m (0.57±0.13). 3500 m (0.49±0.14) and 3000 m (0.5±0.06) had equal soil bulk density. It was significantly different in 4000 m and 3500 m sites. The study found that SBD were significantly different ($p<0.05$). (Table 1, Fig. 3 (B)).

Table 1. Diversity indices and environmental factors of study sites

Diversity indices	Jaljale (4000 m asl)	Gorujure (3500 m asl)	Milke (3000 m asl)
Shannon- Wiener Index (H)	1.008±0.24	1±0.32	1.58±0.22
Simpson Index (D)	0.56±0.09	0.56±0.13	0.76±0.04
Pielou's index (E)	0.61±0.16	0.66±0.18	0.76±.07
Margalef index (S)	4.08±3.9	0.7±0.32	1.25±0.22
Moisture (%)	4.47^{ab}±2.18	4.04a±1.65	6.55^{b}±4.24
Soil bulk density (SBD)	0.57^{a}±0.13	0.49^{b}±0.14	0.5^{ab}±0.06
Soil organic carbon (t/ha)	34.36^{a}±16.2	16.56^{b}±13.15	19.25^{b}±13.08
Total nitrogen (t/ha)	0.74^{a}±0.62	0.5^{ab}±0.28	0.36^{b}±0.16
Aboveground biomass (t/ha)	1.02^{a}±0.32	0.62^{b}±0.16	0.62^{b}±0.24
Belowground biomass (t/ha)	41.62^{a}±2.07	29.17^{b}±8.6	22.04^{b}±5.9
Dicot plant (Individual/m^2)	1411	1688	3444
Monocot plant (Individual/m^2)	13844	7233	5966

This study revealed that soil organic carbon (34.36 ± 16.2) t/ha and total nitrogen (0.74±0.36) t/ha were highest in Jaljale (4000 m asl) and SOC concentration lowest in Gorujure (3500 m asl) (16.56±13.15) t/ha. In contrast, total nitrogen was lowest in Milke (3000 m asl (0.36±0.16) t/ha. Based on total nitrogen of 10-15 cm and 0-5 cm of 4000 m and 3500 m had a significantly different, $p < 0.05$. Comparison of other depth, 3000 m had no significant difference value of nitrogen. In soil organic carbon, 0-5 cm and 10-15 cm of 3500 m had significantly different values ($p<0.01$). 4000 m and 3000 m had no significant difference in SOC value in all depth. Usually, there were generally decreasing soil organic carbon concentration trends with increasing soil depth in all study sites (Fig. 3 (C)). The surface soil layer had high SOC and TN concentrations in all study sites. The differences in SOC concentration of study sites were statistically significant (($p<0.01$).

c) RDA analysis between plant species and environmental variables

This study found a different gradient length at different study areas. The relationship between species variables and environmental variables was analyzed based on gradient length and eigenvalues of DCA1 (Detrended Correspondence Analysis) product. Eigenvalues and axis lengths of DCA1 of 4000 m and 3500 m were less than 0.5 and 2.5, respectively hence analyzed with RDA. It was high in 3000 m hence analyzed with CCA. In ordination, arrows represent environmental factors, with arrow length proportional to each factor's strength. The vector's direction indicates a negative or positive correlation between the element and the axes, and the angle between the two vectors reflects the degree of correlation between variables.

Jaljale area (4000 m asl)

The first axis was positively correlated with SBD, moisture, SOC, AGB, and BGB and negatively with STN, but they were not significantly correlated. Similarly, the second axis was positively correlated with SBD and BGB, negatively with STN, SOC, ABG, and moisture (Fig. 4 (A)).

Soil bulk density (SBD) and below-ground biomass (BGB) were significantly correlated ($r2=0.6$, $p<0.05$). The cumulative percentage of the first three axes of the variance of the species-environment relationship was 19%.

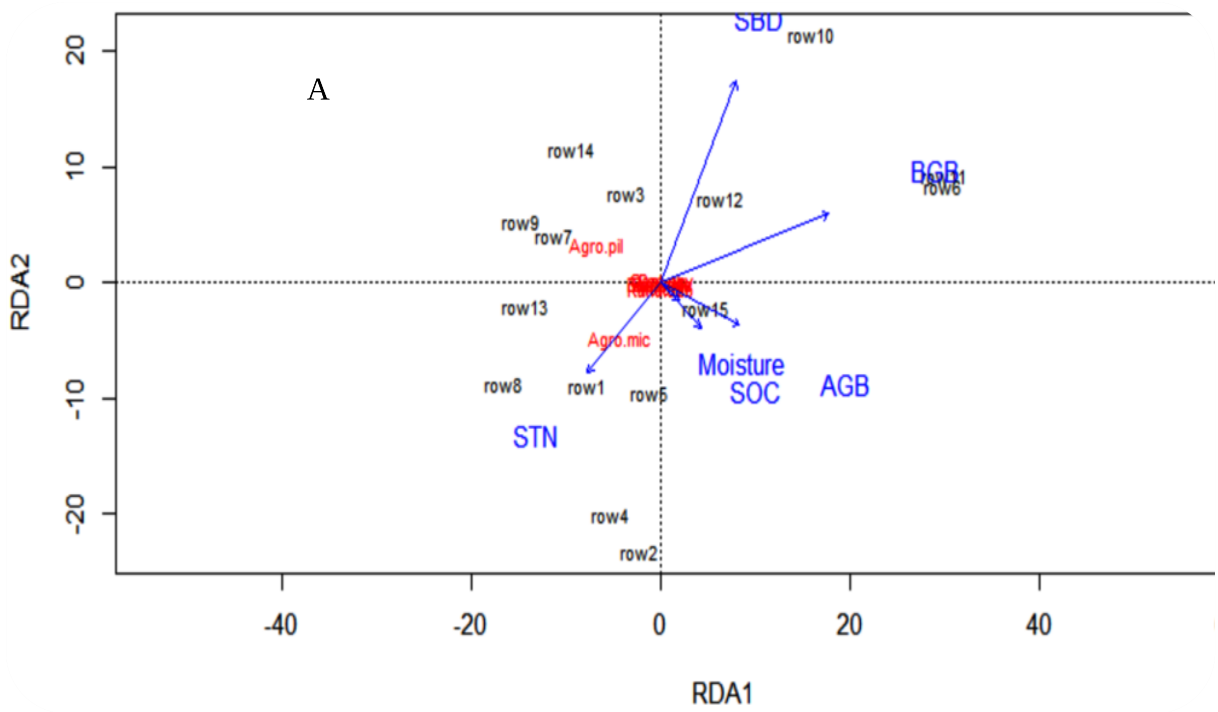
Agrostis micrantha and Agrostis pilosula prefer to grow in high STN-containing soil. Ranunculus adoxifolius grows in SOC and STN-containing moist places.

Gorujure area (3500 m asl)

The first axis was positively correlated with SBD, moisture, SOC, AGB, BGB and negatively correlated with STN ($p<0.05$). Similarly, the second axis was positively correlated with SBD and negatively with STN, SOC, ABG, and moisture (Fig. 4 (B)).

Moisture and soil bulk density (SBD) was significantly correlated ($r2=0.62$, $p<0.01$). The cumulative percentage of the first three axes of the variance of the species-environment relationship was 62.07%.

Carex sp. and Agrostis micrantha prefer to grow in moist places, and Fimbristylis aestivalis grow in dry areas. Carex nubigena and Cynodon dactylon prefer to grow SOC and STN containing soil.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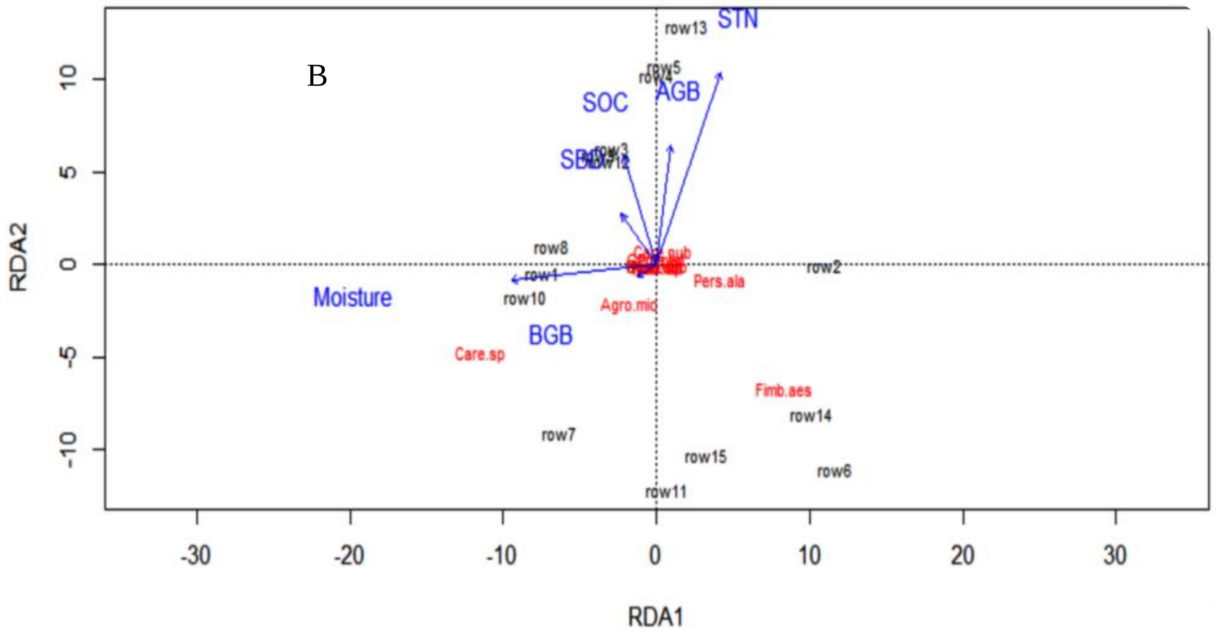
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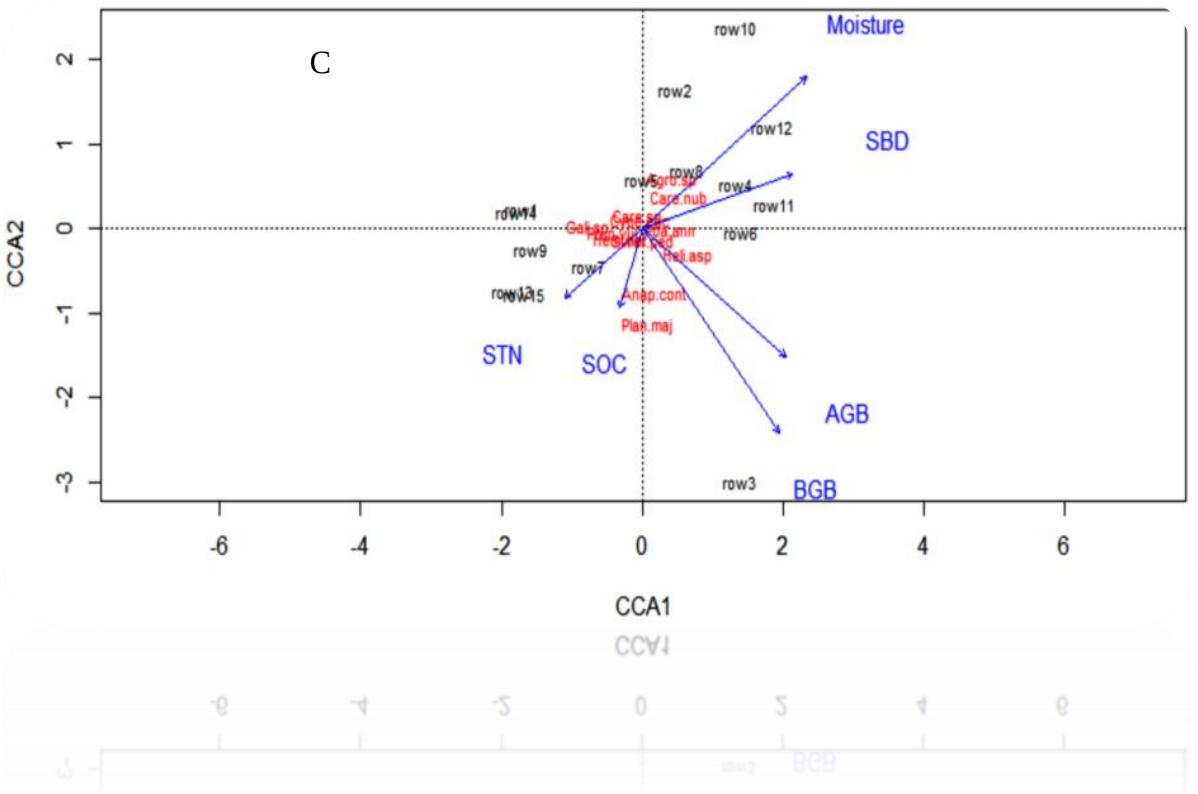

Fig.4. (A) Redundancy Analysis (RDA) ordination results between plant community and environmental factors in 4000, (B) RDA ordination results of plant community and environmental factors in 3500 m, and (C) Canonical Correspondence Analysis(CCA) ordination results of plant community and environmental factors in 3000 m.

Milke area (3000 m asl)

The variables were analyzed with CCA. The first axis was positively correlated with SBD, moisture, AGB, and BGB and negatively with STN and SOC. Similarly, the second axis was positively correlated with SBD and moisture and negatively with STN, SOC, ABG, and BGB. Agrostis sp., Carex sp., and Carex nubigena love to grow moist and high soil bulk density places. Hemiphragma heterophylla Wall., Prunella vulgaris L., Plantago major L. and Anaphalis contorta prefer to grow in high containing of SOC and STN places (Fig. 4 (C)).

Discussions

a) Species diversity and richness

It is found that the higher the altitude lower the plant diversity indices in study sites. Such as the Shannon wiener index (H) is 1.58 in low altitude (3000 m). Pokharel *et al.* (2007), described the same value of plant community indices in the same altitudinal range of Himalaya. Due to topographic conditions, climatic harshness, and edaphic factors, high-altitude regions are not fit for plant growth. A moderate climate is suitable for the growth of most plants. Few plants can grow at high altitudes in harsh climatic conditions. In the mountain flora, species number decreased with altitude, suggesting a relationship between species diversity and productivity (Brown and Gibson 1983; Currie 1991).

The human impact at lower altitudes is grazing activities. It discontinues the introduction and establishment of non-native species (Rawal and Pangtey 1994).High altitude (4000 m asl) is covered by snow for three months of the year and hardly accessible for cattle.

Many plant species found in the Himalayas exhibit varying patterns of distribution. This study revealed that plant diversity decreased with increasing elevation. Austin *et al.* (1996) have found

that the total species richness was most significant at the lower elevation and warmer sites. The extension of the climatic gradient enabled several species to realize their fullest range of elevation adaptability. The high Himalaya region receives low precipitation and temperature with thin soil covered and a very harsh climate. These environmental factors are not suitable for plant growth. Temperature is the primary determinant of altitudinal species richness and decreasing diversity with increasing elevation (Heaney 2001; McCain 2007). Overgrazing, deforestation, temperature, and erosion are the factors responsible for the observed low species diversity (Malik and Malik 2012).

Different environmental factors determined plant communities at different levels of elevation. 4000 m and 3500 m were affected mainly by elevation and SOC whereas 3000 m appears to be mostly structured by moisture and SBD. This suggests that different soil properties, and ecological drivers limit plant distribution. This was reflected in the index of plant communities between the three areas. The cumulative percentage of the variance of the species-environment relationship was high in 3500 m (62.07%) because the mid-region has a suitable species-environment relationship.

b) Phytomass

Phytomass depends on major factors like temperature, moisture content, soil texture, photosynthesis, microbial activity, and available nutrients. Phytomass productivity of grassland/rangeland has been reported variable in different places.

The result of the study depicted large spatial variations in both Above Ground Phytomass (AGB) and Below Ground Phytomass (BGB). Phytomass of the study site was slightly higher than the upper Mustang rangeland (Maharjan 2010), Annapurna Conservation Area, Manang, Nepal (Bhattarai *et al.* 2004), and central Himalayan high altitude grassland in India (Ram *et al.* 1989). It was significantly higher than the Alpine steppe and alpine meadow of the Tibetan plateau (Yang *et al.* 2009; Liu *et al.* 2017).

The above comparison revealed that Eastern Himalaya (Nepal section) has a relatively high value of phytomass than western Himalaya (Gaarhawal Himalaya) and Tibetian plateau. Eastern Himalaya region is a wet and humid region having more precipitation than the western Himalaya region. Further, the Tibetian plateau is the rain shadow of the Himalayas and having less precipitation.

The high-altitude rangeland (Jaljale) has a high amount of AGB and BGB compared to low altitude rangeland (3000 m). It is noticed that fewer grazing animals can access high altitude rangeland compared to low altitude rangeland. AGB was relatively less than BGB because of the high intensity of grazing and tramping of herbivores and grassland burning in the study sites. Precipitation is the main determinant of phytomass production in mountain areas. Nevertheless, further drivers may modulate the precipitation effect on phytomass, including soil nutrient relations or biotic interactions (Stegen *et al.* 2011; Metcalfe *et al.* 2014).

This report did not show the hump-shaped relationship between aboveground phytomass and altitude. It was a linear negative relationship between phytomass and altitude due to declining temperature and nutrients with altitude (Rastetter *et al.* 2004; Namgail *et al.* 2012).It is possible that trampling and overgrazing by domestic livestock at the lower slopes deplete plant resources. This is tenable because livestock grazing is known to decrease plant phytomass in central Asian alpine rangelands (Zhou *et al.* 2006).

The plant communities of high altitude were largely dominated by less palatable species like *Stipa* spp. that help to increase phytomass.

There was a large number of monocot plant species in high altitude rangeland than in low altitude. The rangeland area

was predominated with monocot plants Carex sp. and Agrostis pilosula species.The root of monocot plants grow profusely at the upper layer of soil and contribute large belowground phytomass on rangeland. This study showed that the density percentage of the monocot plant revealed increasing order from low altitude, 3000 m (5966 plants/m2), to high altitude rangeland, 4000 m (13844 plants/m2). Thus plant density influenced phytomass on rangeland.

c) Soil physicochemical properties

In the present study, BD was high at high altitudes and low at low altitudes. A similar type of result was reported by Debnath *et al.* (2012) in Sikkim. The higher BD at top altitudes is a good indication that soils have occupied the coarser structure of organic matter and enrich the spaces by soil organic carbon (Kumar *et al.* 2010 and Garhwal *et al.* 2013).

This study showed low altitude had high Soil moisture (SM) value and high altitude had less value. There are Rocky Mountains in high altitude and less organic matter, whereas soil of low altitude is humus and young. It was high in the rainy season and low in the dry season. The more exposed areas might have contributed to the lower value of soil moisture (Sigdel *et al.* 2015).

Shrestha (2016), Saeed *et al.* (2015), Debnath *et al.* (2012), and Xu *et al.* (2018) stated that the SOC value increased as elevation increases but it gradually decreased with increasing soil depth. Similar trend was observed in the present study. As there is higher organic matter in the top layer soil, the percent of organic carbon is also higher. The soil organic carbon increased with increasing altitudes due to suitable moisture percent, which is a good indicator of higher soil organic carbon (SOC) in the soil (Kumar *et al.* 2010).

Results of the study sites depicted high total nitrogen in high altitude; however the value increased with increasing soil depth. This may be due to suitable conditions for proliferating nitrogen-fixing bacteria. Higher nitrogen content in bottom soil is due to the non-disturbance of nitrogen fixation bacteria and a lower rate of leaching nitrates. The decomposition rate is very slow in high-altitude sites due to low temperature. Hence organic matter persists for a long time.

It is concluded that the diversity indices of plant community in the Himalayan rangeland were negatively correlated with elevation because of edaphic factors, climatic factors, anthropogenic and topographic position. On the contrary, phytomass and soil nutrients (organic carbon and total nitrogen) were high value in high elevation on account of fewer disturbances and trampling.

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