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Effects of Continuous Slope Gradient on the Dominance Characteristics of Plant Functional Groups and Plant Diversity in Alpine Meadows

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Abstract: Many studies reported the effect on plant functional groups and plant diversity under discontinuous slope gradient. However, studies on the effect of continuous slope gradient on plant functional groups and plant diversity in alpine meadows have rarely been conducted. We studied the effect of a continuous slope gradient on the dominance characteristics of plant functional groups and plant diversity of alpine meadows on the Tibetan plateau—in Hezuo area of Gannan Tibetan Autonomous Prefecture. Altogether, 84 samples of alpine meadows grass and 84 soil samples from seven slope gradients at sunlit slopes were collected. By using analysis of variance (ANOVA) and Pearson correlation coefficient, this study revealed: (1) Continuous slope gradient is an important factor affecting plant communities in alpine meadows, due to the physical and chemical characteristics of the soil and water content. The number of families, genera, and species increased first then decreased at the different slope gradient levels, respectively; (2) there is a close relationship between the soil and plant functional groups, and plant diversity. In other words, the slope determines the functional groups of plants and the soil nutrients; and (3) soil characteristics (pH value, Soil Total Nitrogen, Soil Water Content) are the determining factors of the plant community characteristics at each slope gradient level. To conclude, a continuous slope gradient is an important factor that affects plant communities in alpine meadows.

Keywords: continuous slope gradient; alpine meadows; plant functional groups; plant diversity; soil nutrients; Tibetan plateau

1. Introduction

The distribution and functional characteristics of vegetation are determined by zonal climatic conditions at regional and even global scales [1,2]. The topography not only redistributes water, heat and soil nutrients [3,4], but also affects the patterns and characteristics of vegetation at the landscape scales [5,6]. Therefore, topographic factors play an important part in effecting the functional characteristics and diversity of vegetation. Slope as one of the main topographical factors, not only has a great impact on the quantity and function of plant communities, but also a key abiotic factor in plant diversity and soil nutrient change. The effects of slope on plant communities are mainly reflected in the growth conditions and soil erosion of plant communities [7], common plants [8], species numbers [9], plant community characteristics, community diversity [10], and vegetation distribution patterns [11], and so on. Using slope to study vegetation characteristics and diversity distribution has become a prerequisite for revealing the relationship between topography and vegetation.

Alpine meadows are mainly distributed in mountainous areas and plateaus, even on areas maintained by harsh climatic conditions. As one of the main vegetation types in the middle and eastern parts of the Tibetan plateau, alpine meadows have important ecological value for maintaining the ecological balance and the development of animal husbandry of the Tibetan plateau. Numerous studies have been conducted in the field of the effects of topographic factors on the characteristics of plant communities in alpine meadows [12]. At present, previous studies have shown that altitude is an important topographic factor that causes plant community changes [13] and alpine meadows formation [14], while slope direction is the determinant of plant diversity, distribution pattern and functional traits in alpine meadows [15]. However, there is no relevant research on how the slope factor affects the plant community in alpine meadows, and the difference in the slope of the vegetation and its mechanism are still unclear in alpine meadows.

Therefore, in our study, we took the mountain vegetation of the sunny slope in alpine meadows in the eastern margin of the Tibetan plateau as the research object. The specific objectives were to reveal the influence mechanism of continuous sunny slope on the vegetation and soil characteristics of alpine meadows, based on the analysis of plant community characteristics and the physical and chemical properties of the soil under slope gradient. The study will provide more information on the sustainable use and restoration of alpine vegetation in alpine meadows and have an important ecological value in maintaining ecological balance and animal husbandry in the minority area.

2. Material and Methods

2.1. Study Area

The study area is distributed in the suburb of the eastern margin of the Tibetan plateau in Gansu province, China ($34^{\circ}57'23.16''$ – $34^{\circ}57'26.09''$ N, $102^{\circ}52'50.89''$ – $102^{\circ}53'43.57''$ E) (Figure 1). The survey area was selected without interference from farming, which belongs to the summer pasture with the altitude from 2936 to 3100 m and an area of approximately 1 km². According to the government website [16], the regional climate is characterized by a long cold season, with a mean annual temperature between -0.5 and 3.5 °C, the extreme maximum temperature of 28 °C, and the extreme minimum temperature of -24 °C. The mean annual precipitation is 545 mm, the annual evaporation is 1222 mm, and the average frost-free period is 48 days. Hence, the study area is a typical alpine region with plateau continental monsoon climate. In addition, the vegetation of this region harbors very large plant diversity, including *Stipa purpurea*, *Festuca sinensis*, *Brachypodium sylvaticum* var., *Carex crebra*, *Kobresia humilis*, *Scirpus pumilus* and *Sanguisorba filiformis*, *Polygonum viviparum*, *Bupleurum smithii* Wolff, *Astragalus polycladus*, *Vicia unijuga*, etc.

2.2. Methods

2.2.1. Sampling Design

To study the relationship between slope and the vegetation community in alpine meadows, we selected the sunny slope of a small-scale mountain as the basic terrain unit as the survey object. The vegetation survey was conducted from 15 July to 1 August 2017. In our study, the study area was required to meet three conditions as follows: Sunny slope, with the similar inter-annual grazing intensity, and no cropping interference. Firstly, a total of seven plots were sampled according to the slope gradient based on the Digital Elevation Model (DEM). Then, approximately 2×10 m² belts selected in each plot, based on the characteristics of topographical factors (mainly the slope direction and elevation). Each vegetation plot consisted of 12 quadrats of 0.5×0.5 m² of inventory herb, and of eight quadrats of 2×2 m² of shrub, in the alpine meadows. Herbs in quadrats of grasslands were counted, and their heights and percent cover were measured. In addition, a variable measured or collected at each plot, including plant species, species quantity, vegetation cover, plant height, plant frequency, and other related indicators. Furthermore, a soil sample was randomly collected with

a 35 mm internal diameter, 20 cm depth and repeated 10 times at each sample. Then, a mixture of the soil samples at each sampling plot was used as a soil sample. The total vegetation samples number was 84 at a different slope. Besides, the total of 84 soil samples from the same survey area was collected. Moreover, measure and record the altitude, latitude and longitude, soil, vegetation type and interference status of each sample. In addition, the slope of the survey sample basically covers each slope gradient.

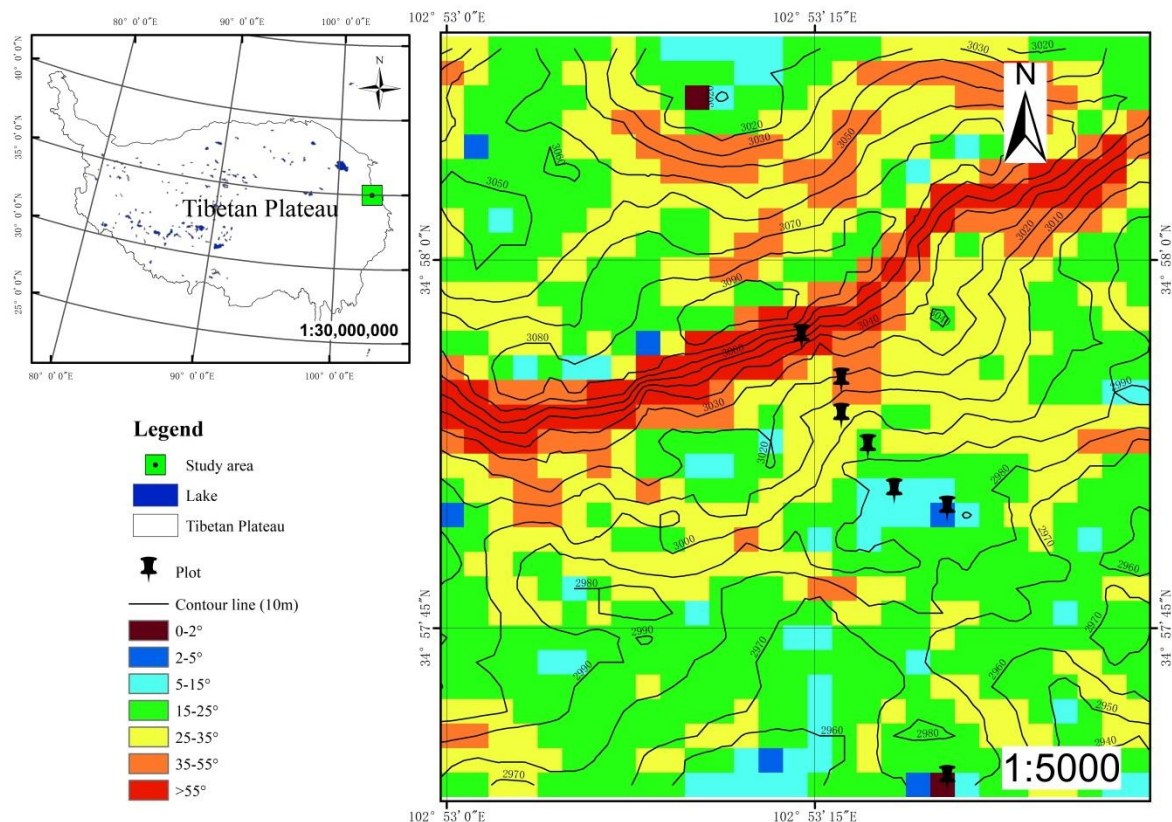


Figure 1. The location of the study area.

2.2.2. Data Analysis

According to the grassland plant economic group and plant types [17–19] the classification criteria, all the species were divided into six functional groups based on the utilization properties of alpine meadow plants in the study area, including *Shrubs/Subshrubs* (SS), *Sedge family Herbage* (SH), *Perennial Bunch-grass* (PB), *Perennial Rhizome forbs* (PR), *Perennial Forbs* (PF), and *Annuals/Biennials* (AB).

In addition, the slope was divided into seven gradient levels [20], that is I [0–2°], II (2–5°), III (5–15°), IV (15–25°), V (25–35°), VI (35–55°), and VII (55–90°).

Dominance (Summed Dominance Ratio SDR_3 of three factors) for shrubs and herbs were calculated as follows [21]:

$$SDR_3 = (\text{relative height} + \text{relative overage} + \text{relative density})/3,$$

where SDR_3 means the summed dominance ratio of the species; relative height, relative coverage and relative density refers to the proportion of one species accounting for the sum calculated for each plot individually.

The species diversity was assessed by calculating different indices. The Species richness index (R), the Simpson index (D), the Shannon's diversity index (H) [22] and the Pielou's index of evenness (E) [23] were calculated using the following equations:

Species richness index (R)

$$R = S. \quad (1)$$

Simpson's diversity index (D)

$$D = 1 - \sum_{i=1}^s p_i^2. \quad (2)$$

Shannon-Wiener diversity index (H)

$$H = -\sum_{i=1}^s P_i \log P_i. \quad (3)$$

Pielou's index of evenness (E)

$$E = \frac{H}{\ln S}, \quad (4)$$

where $P_i = N_i/N$, P_i is the proportion of individuals found in the i th species, S is the total number of species, and N is the total individuals of all species present.

To estimate the relationship between slope gradient and the physical and chemical characteristics of the soil, five factors were chosen to investigate the soil characteristics, including Soil pH value (pH), Soil Organic Matter (SOM), Soil Total Nitrogen (STN), Soil Total Potassium (STK) and Soil Water Content (SWC). The determination of soil samples were analyzed as follows: (1) pH value was measured by 1:1 soil suspensions with a pH meter; (2) SOM was determined by Walkley and Black Rapid titration method [24]; (3) STN in 0.5 g soil samples by digestion with sulphuric acid and a K_2SO_4 : $CuSO_4$: Se catalyst; (4) STK was determined using NaOH fusion method; (5) using spectrophotometer, the absorbance was measured at 660 nm, SWC was measured at the depth of 20 cm as $SWC = (mass_f - mass_d)/mass_f$, where $mass_f$ is the fresh mass of soil, while $mass_d$ is the dry mass of soil.

2.2.3. Analysis Methodology

Community evenness was compared by producing dominance-diversity [22] plots using the vegan package in program R. A one-way ANOVA was applied to determine significant differences between different index using SPSS 16.0 (SPSS Inc., Chicago, IL, USA). Furthermore, the relationship between soil factors and plant traits were analyzed by Pearson's correlation coefficient. The linear graph was done by OriginPro 2017 software (OriginProLab Corporation, Northampton, MA, USA, 2017).

3. Results

3.1. Analysis of the Plant Species and Community Quantitative Characteristics of Sunny Slope

Altogether, 84 samples of alpine meadows grass from seven slope gradients in sunny slope were collected. There were 27 families, 101 genera and 134 species distributed in sunny slope survey plots, among which 11 species were *sedge family herbage* (SH), nine species were *Perennial Bunch-grass* (PB), 10 species were *Perennial Rhizome forbs* (PR), 76 species were *Perennial Forbs* (PF), 21 species were *Annuals/Biennials* (AB), and 4 species were *Shrubs/Subshrubs* (SS).

As shown from Table 1, the number of families, genera, and species increased first then decreased at the different slope gradient level, with the peak at level IV (15–25°), IV (15–25°), III (5–15°), respectively. *K. humilis* was the dominant species at the slope gradient level I [0–2°], and V (25–35°), respectively. Furthermore, *E. nutans* was a sub-dominant species at each slope gradient level, but it was dominant at level IV (15–25°) and VI (35–55°), with the dominance was 19.29% and 14.67%, respectively. *S. capillata* was the main associated species at slope gradient level I [0–2°], and it became the dominant species at level II (2–5°) and III (5–15°) then the dominance gradually decreased. *P. pratensis* was the main companion at each slope gradient level. *Perennial weeds* become the main companion species in

different gradients, such as *P. fragarioides*, *M. ruthenica*, *S. chamaejasme*, and *T. mongolicum*, and so on. Although the dominant species distributed at different slope gradient level, the dominance values of the dominant species were small with huge fluctuations. Therefore, the distribution of dominance was relatively fragmented, and the dominant position of the species was not prominent in the study area (Table 1).

3.2. Effects of Slope Differentiation on Plant Community and the Physical and Chemical Properties of Soil

3.2.1. Effect of Slope on the Composition of Plant Functional Groups

The Plant Functional Groups (PFG) concept was used as a framework for investigating the linkages between ecosystem functions and plant biodiversity.

As shown in Figure 2, at different slope gradient level, the dominance of SH increased first then decreased with the highest dominance was at V slope gradient level ($p < 0.01$). The dominance of PR was low and changed mild at I–V slope gradient level, however, which increased significantly at VI–VII slope gradient level ($p < 0.05$). In addition, the dominance of PB obviously decreased with a significant difference at each slope gradient level ($p < 0.01$); and there was no PB detected at level VII. The dominance of PF maintains superiority with difference fluctuation at each slope gradient level ($p < 0.01$). The dominance of AB was changed with huge fluctuations and significant differences at each slope gradient level ($p < 0.01$). There was no related species of SS at I–IV slope gradient level, while the dominance of SS was increased obviously with a significant difference at V–VII slope gradient level ($p < 0.01$).

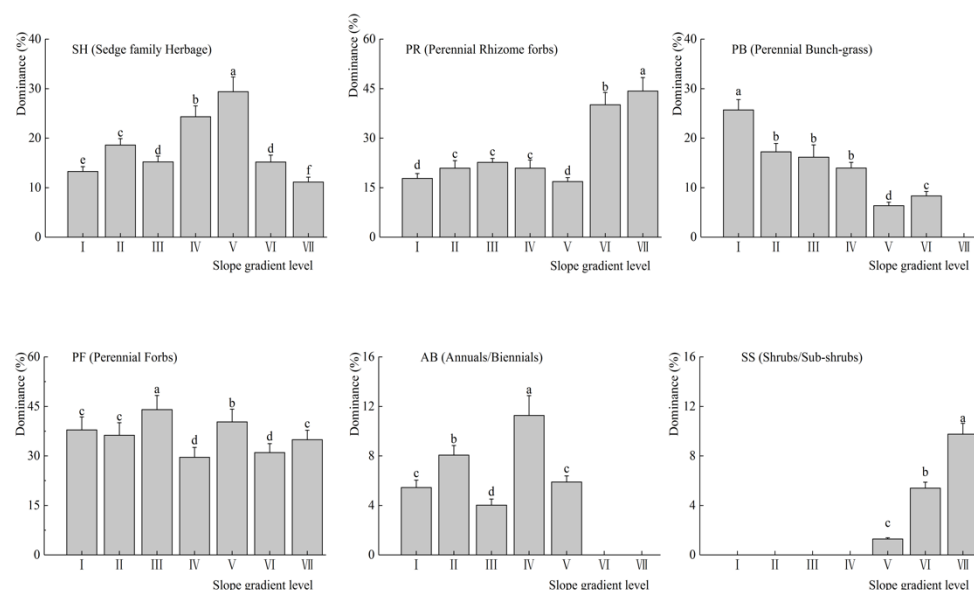


Figure 2. Cumulative dominance values of life-form functional groups under different micro-topographic conditions (mean $\pm$ SE). All variables were examined using ANOVA with Tukey's test $\alpha = 0.05$. Bars with different letters indicate differences between sampled slopes. the same below.

Table 1. Composition of plant families and species under different slopes.

Gradients	I	II	III	IV	V	VI	VII
Family	9	12	16	15	13	8	7
Genus	23	25	31	35	26	14	10
Species	19	32	36	41	35	17	11
Important species	<i>K. humilis</i> (14.74%)	<i>S. capillata</i> (7.96%)	<i>S. capillata</i> (12.92%)	<i>E. nutans</i> (19.29%)	<i>K. humilis</i> (14.33%)	<i>E. nutans</i> (14.67%)	<i>F. arioides</i> (24.38%)
	<i>P. pratensis</i> (13.02%)	<i>E. nutans</i> (6.74%)	<i>E. nutans</i> (9.60%)	<i>K. humilis</i> (9.08%)	<i>E. nutans</i> (8.46%)	<i>P. pratensis</i> (13.74%)	<i>K. capillifolia</i> (11.13%)
	<i>S. capillata</i> (12.37)	<i>P. pratensis</i> (6.71%)	<i>K. cristata</i> (6.44%)	<i>T. mongolicum</i> (8.21%)	<i>K. capillifolia</i> (7.43%)	<i>L. japonicum</i> (8.87%)	<i>S. hieracioides</i> (9.85%)
	<i>P. fragarioides</i> (11.16)	<i>M. ruthenica</i> (6.55%)	<i>S. chamaejasme</i> (5.79%)	<i>P. pratensis</i> (7.59%)	<i>S. chamaejasme</i> (5.05%)	<i>K. humilis</i> (7.20%)	<i>C. adpressus</i> (9.75%)
	<i>E. nutans</i> (10.10%)	<i>K. humilis</i> (5.66%)	<i>K. humilis</i> (4.73%)	<i>S. chamaejasme</i> (7.40%)	<i>P. pratensis</i> (4.55%)	<i>F. arioides</i> (6.69%)	<i>G. macrophylla</i> (8.13%)

3.2.2. Effect of Slope Gradient on Plant Diversity

The effect of slope on the habitat can be reflected by plant diversity. As described in Figure 3, the richness index (R) increased first and then decreased with the increase of slope gradient level ($p < 0.01$). Furthermore, Shannon-wiener index (H) decreased with the slope gradient level increased. However, there was a significant difference of Shannon-wiener index (H) at each slope gradient level ($p < 0.05$). Similarly, the higher the slope gradient level, the lower the Simpson's diversity index (D). There was no significant difference effect on the Simpson's diversity index (D) at each slope gradient level ($p > 0.05$). In addition, the Pielou's index of evenness (E) was lower at the slope gradient level IV than that at other slope gradient level ($p < 0.05$).

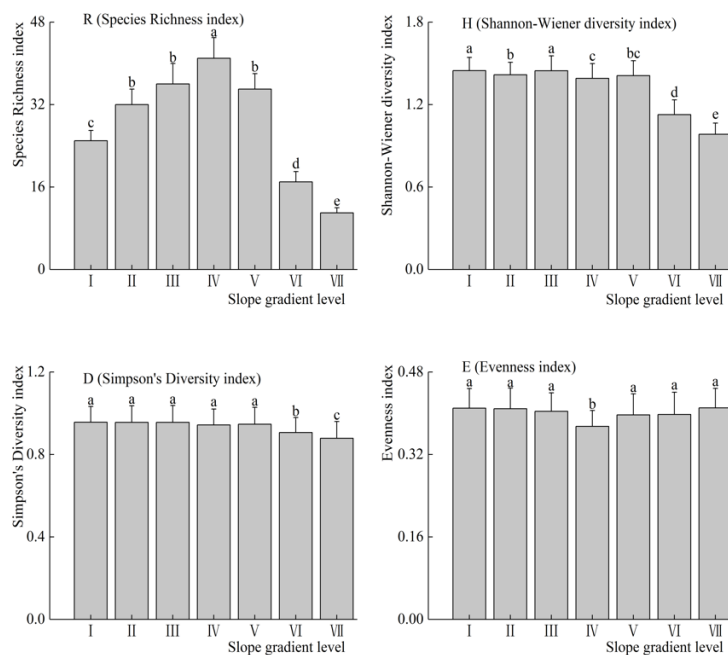


Figure 3. Plant diversities at each slope gradient level (mean $\pm$ SE).

3.2.3. Effect of Slope on the Physical and Chemical Characteristics of Soil

Figure 4 shows the effect of slope on the physical and chemical characteristics of the soil. The pH value slightly increased with slope gradient level increased ($p < 0.05$). In addition, Soil Organic Matter (SOM), Soil Total Nitrogen (STN) and Soil Water Content (SWC) were obviously decreased with the slope gradient increase at each slope gradient level, respectively ($p < 0.05$); and the Soil Total Phosphorus (STP) increased with the slope gradient increase with no significant difference at each slope gradient level ($p > 0.05$). However, Soil Total Potassium (STK) decreased first and then increased with the slope gradient increased ($p < 0.01$).

3.3. Correlation Analysis

3.3.1. Correlation Analysis between the Characteristics of Plant Functional Groups and Soil Factors

As can be seen from the data in Table 2, under different slope gradient level, the physical and chemical characteristics of the soil had a greater effect on the plant functional groups. The correlation was significant between plant functional groups and the physical and chemical characteristics of the soil. The results showed that SS has a highly significant negative correlation with STN, while the highly significant positive correlation with SWC, and pH, respectively. SH has a highly significant negative correlation with STK; and PR has a highly significant negative correlation with SWC, while the significant positive correlation with pH and the significant negative correlation with STN, respectively. In addition, a highly significant positive correlation was observed between PB and SOM,

STN and SWC, respectively. However, PB had a highly significant negative correlation with PH. The correlation between the physical and chemical characteristics of the soil with PF, and AB was no significant, respectively.

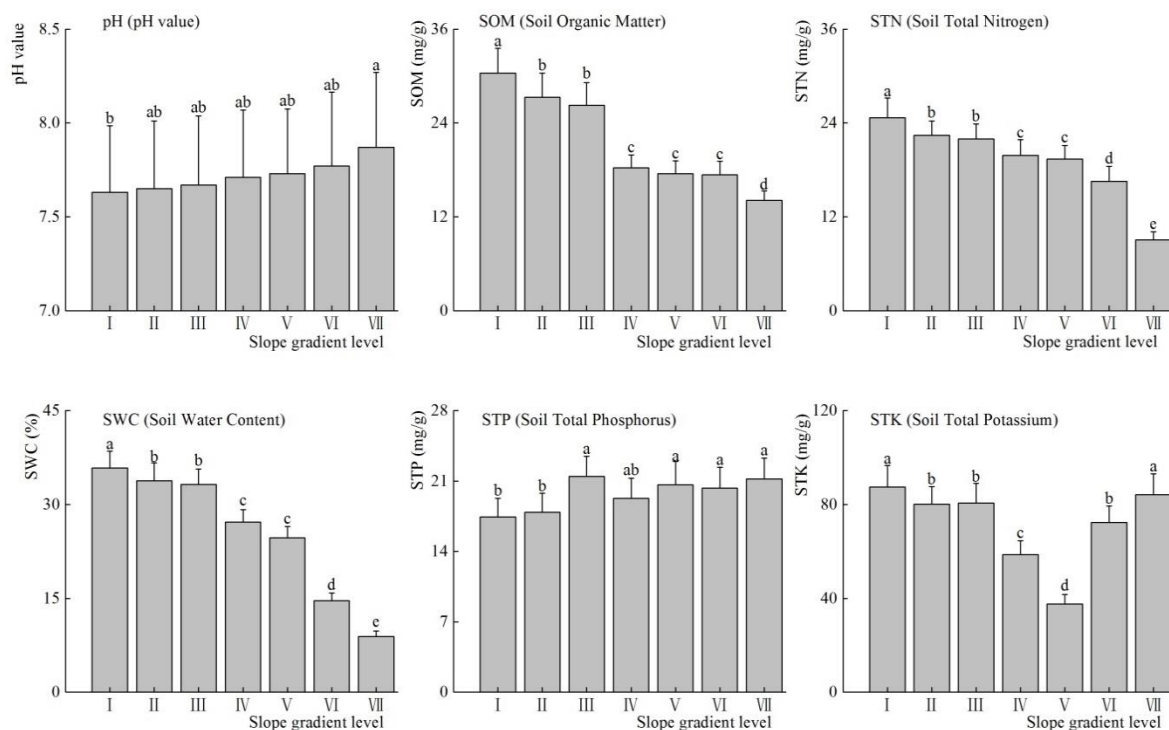


Figure 4. Cumulative dominance values of life-form functional groups under different micro-topographic conditions (mean ± SE).

Table 2. The correlation matrix between plant communities and soil factors.

	SS (Shrubs/Sub-Shrubs)	SH (Sedge Family Herbage)	PR (Perennial Rhizome Forbs)	PB (Perennial Bunch-Grass)	PF (Perennial Forbs)	AB (Annuals/Biennials)
pH-value (PH)	0.939 (**)	−0.185	0.855 (*)	−0.914 (**)	−0.355	−0.621
Soil Organic Matter (SOM)	−0.709	−0.219	−0.654	0.912 (**)	0.453	0.343
Soil Total Nitrogen (STN)	−0.951 (**)	0.259	−0.870 (*)	0.894 (**)	0.349	0.615
Soil Total Phosphorus (STP)	0.506	0.010	0.327	−0.552	0.242	−0.528
Soil Total Potassium (STK)	0.205	−0.941 (**)	0.270	0.368	0.042	−0.356
Soil Water Content (SWC)	0.942 (**)	0.202	−0.913 (**)	0.902 (**)	0.453	0.672

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Above all, we can see that the characteristic of plant functional groups was closely related to the physical and chemical characteristics of the soil. In other words, the spatial heterogeneity of the physical and chemical characteristics of the soil affected by slope gradient has a significant impact on the plant functional groups. Furthermore, pH, STN, and SWC were the main characteristics of the soil, which were closely related to the plant functional groups.

The spatial heterogeneity of the physical and chemical properties of the soil, due to slope, had a significant impact on plant functional groups. There was a close relationship between the soil and plant functional groups, and plant diversity. In addition, pH, STN and SWC were the determining factors for plant community characteristics at each slope gradient level.

3.3.2. Correction Analysis between Plant Diversity and the Physical and Chemical Characteristics of Soil

As shown in Table 3, under the slope gradient level, the physical and chemical characteristics of the soil had a greater effect on plant diversity. There was a significant positive correlation between D and SWC, and STN, respectively, but an extreme significant negative correlation between D and

PH ($p < 0.01$). In addition, a significant correlation was observed between D and SOM ($p < 0.05$). Furthermore, H has a significant positive correlation with SWC, and STN, respectively, but an extreme significant negative correlation with PH ($p < 0.01$). However, the physical and chemical characteristics of the soil have no significant correlation with R and E, respectively ($p > 0.05$). The results showed that PH, STN and SWC were the main characteristics of the soil, which has the closed related with the plant diversity.

Table 3. The relationship between plant diversity and soil.

	R (Species Richness Index)	D (Simpson's Diversity Index)	H (Shannon-Wiener Diversity Index)	E (Pielou's Index of Evenness)
pH-value (PH)	−0.661	−0.951 (**)	−0.925 (**)	−0.007
Soil Organic Matter (SOM)	0.334	0.764 (*)	0.718	0.398
Soil Total Nitrogen (STN)	0.683	0.959 (**)	0.938 (**)	−0.057
Soil Total Phosphorus (STP)	−0.168	−0.496	−0.457	−0.084
Soil Total Potassium (STK)	−0.491	−0.170	−0.224	0.620
Soil Water Content (SWC)	0.717	0.965 (**)	0.951 (**)	0.022

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

4. Discussions

4.1. The Difference of the Plant Functional Groups at Each Slope Gradient Level

The plant functional groups combined of all plant species responding to abiotic and biotic environmental constraints in ecosystems or biomes based on plant traits [25]. The dynamic and stable community structure formed by plant functional groups is a comprehensive adaptation of environmental factors, such as topography and soil. This specific structure is the basis for maintaining the functions and processes of vegetation ecosystems.

Slope affected plant functional groups, directly or indirectly, by changing ecological factors, such as partial moisture, heat, light intensity, and the physical and chemical characteristics of the soil. A previous study proved that topographic factors, such as slope, have a significant influence on the spatial distribution of vegetation, which was the main factor affecting plant species composition, soil and water conditions in alpine meadows [26]. According to Table 1 and Figure 2, under the influence of the slope, the dominance change of alpine meadow plant community was not obvious while the dominant degree of the plant functional groups changes extremely obvious in the survey area. Different plant functional groups have different topographical choices [27]. *Shrubs/Subshrubs* plants (SS), and *Perennial Rhizomes* (PR) gradually tends to dominant above the slope gradient level IV (15–25°). While, the plant dominance of *Sedge family Herbage* (SH), *Perennial Bunch-grass* (PB), and *Annuals/Biennials* (AB) was declined above level IV, respectively (Figure 2). With the increase of the slope gradient, the composition of plant communities is gradually simplified. Therefore, as the slope gradient increases, other species are almost impossible to find. The slope becomes one of the limiting factors of the plant community. For example, *Cotoneaster adpressus* Bois can grow in thin soil and above 25°, which was an adaptation of the plant habitats, and therefore has the effect of indicating the slope.

The effects of soil erosion and nutrient loss were irreversible, so nutrient changes often have continuity between different slope gradient levels (Figure 4). In addition, the types and quantities of nutrient elements required for the normal growth of different plants have differentiation characteristics [28]. However, the differentiation characteristics affected on the species distribution and the plant functional groups. If the soil nutrient types and contents changed, the grassland plant community components may change to some extent [29]. Then, the original species will be replaced by other species that are better suited to the new soil conditions [30]. As a result, plant functional groups have changed. The plant community has good adaptability through the recombination of different plant functional groups and the adjustment of species within the plant functional groups at different slope gradient level. In our study, there were two plant communities (AB and PF) had little affected

by the physical and chemical properties of the soil (Figure 2), indicating that they easy to occupy and utilize any kind of soil resources and grow rapidly.

4.2. The Plant Diversity at Each Slope Gradient Level

Plant diversity was an important parameter for characterizing community structure, which not only reflected changes in species composition within the community, but also characterized community habitat differences and stability [31,32].

In the study area, plant diversity was affected by the slope, because the soil and water condition were rich in the habitat on the lower part of the slope, therefore, the plant diversity was high. The soil and water conditions were poor in the steeper slope; therefore, the plant diversity was low. In addition, the change of the plant community diversity was caused by the habitat heterogeneity [33]. Greater slope inclination further worsens the conditions leading to diminished diversity [34]. Some studies reported that greater slope inclination further worsens the conditions prevent competitive species from monopolizing resources, resulting in an increase in plant diversity [35–37]. We have observed that the index (plant richness index (R), the Simpson's diversity index (D), and the Shannon-wiener index (H)) began to decrease at the slope gradient level V (25–35°), due to the soil nutrient and root distribution spatial condition deteriorated with the slope increased (Figure 3). Although the dominance of some plant functional groups increased (such as PR and SS, shown in Figure 2), even some perennial weeds can also become a single dominant species community.

Ecosystems with high plant diversity contained species that are resistant to the specific environmental disturbances, which can compensate for the disturbances on the ecosystems [38]. Some studies have shown that the regular changes in plant diversity index can reflect the stability of the community [38–40]. The composition of plant species is different at each slope gradient level, so the values of various diversity indices appear irregularly in the study area. As shown in the fourth subfigure in Figure 3, at the level IV, the dominance of some species is extremely obvious with high superiority and low uniformity, indicating that the dominant species of plant communities at the slope gradient are prominent, which increases the instability of the community. Changes in the evenness index may be strongly influenced by biotic or abiotic factors [41].

Some studies have shown that grazing leads to reduced species diversity and species uniformity [42–45], but significantly increases species dominance. In other words, the community stability affected by the consequences of grazing [46–48]. Soil infertility factors limit the growth of plant populations [49]. Similarly, the physical and chemical properties of the soil at different slope gradient also can limit the growth of populations of plants. In addition, other factors, such as interspecific competition among plants, and coevolution of animals and plants, et al. will also have an impact on community diversity.

The irregularity of alpine meadow plant community characteristics was caused by many reasons along slope gradient. At present, we mainly choose the slope factor to explain the irregularity of the plant community characteristics in alpine meadows. It is also an incomplete performance in the single factor study of the terrain. Under the gradient, irregularity will conduct a more in-depth analysis in the study of grazing disturbance in alpine meadows.

4.3. The Physical and Chemical Characteristics of Soil at Each Slope Gradient Level

The physical and chemical properties of the soil not only determine the process of vegetation growth and decomposition of plant residues, but also affect the development of plant communities at each slope gradient level. Previous studies reported that the soil characteristic (STP, SOM, SWC, and pH value) has an impact on the growth of aboveground vegetation. Among all above soil characteristics, the two main factors are pH value and SWC [50,51].

In our study, SOM declined with the increase of the slope gradient, while pH value increased with the slope gradient increased. The reason might be that the soil erosion is serious that aggravates the loss of soil nutrients in alpine meadows [52–54]. Thus, the loss of SOM and soil nutrients increased

with the increase slope gradient, which is more obvious in the steeper slope. However, litter releases a large amount of organic acid during the process of decomposition at gentle slope, and thus reduces the pH value of the soil [55]. In other words, pH and SOM have opposite trends with the increase of the slope gradient, which is consistent with our findings. In addition, SWC declined with the increase of the slope gradient in our study. Some studies [56,57] also reported that SWC is lower in the steeper slope than that in the gentle slope. The reason might be that the SWC is lower due to the water loss in the steeper slope, while SWC increased because of the long-term accumulation of soil moisture in the gentle slope [58–60].

Furthermore, we found that Soil Total Phosphorus (STP) increased with the slope gradient increases (Figure 4), which agree with a previous study [61]. We also found STN declined with the slope gradient increased (Figure 4), the result consistent with some previous studies [62].

4.4. The Relationship between Plant Community Characteristics and the Physical and Chemical of Soil

It is well-known that plants absorb nutrients and water through the soil, thus the relationship between plants and soil is more direct than the relationship between plants and terrain [63]. The soil was the nutrient source for vegetation, therefore, changes in the physical and chemical characteristics of the soil, and its distribution, has a great impact on plant growth. There is a significant correlation between the characteristics of vegetation and the soil [27]. In our study, the characteristics of plant functional groups were significantly correlated with the physical and chemical characteristics of the soil at each slope gradient level (Table 2). Similarly, plant diversity was closely related to the physical and chemical characteristics of the soil at each slope gradient level (Table 3). We found that the plant diversity showed a positive correlation with SOM; but significant negative correlation with pH value. These findings were also in line with a previous study [64]. Plant functional groups and diversity are closely related to a few soil factors. N and P are the main growth-limiting nutrients for plants in natural environments. Both elements play an essential role in plant growth. In most terrestrial ecosystems, the process of the ecosystems was limited by N and P cycles [65]. The content of phosphorus and potassium in the soil has an important impact on the species diversity of tropical plant communities [66]. Increasing the content of N in soil will enhance the primary productivity of the community, but significantly reduce the diversity of community species [67]. Therefore, high content of phosphorus in soil is considered as one of the main factors limiting species diversity on grasslands [68]. Gradients of soil depth and water availability were found to be the main factors influencing plant composition patterns. The main growth-limiting nutrients of the Tibetan plateau were N and P [69]. The changes in the quantity and composition of available nutrients of N and P have a significant impact on the species composition and community structure of plant communities [29]. In our study, soil total nitrogen, pH and water on different slopes of alpine meadows are the main factors determining plant functional groups and plant diversity.

When plant species change significantly in plant communities, plant diversity may change [70]. Plant communities might variance the content of some nutrient elements in soil, which leads to dynamic changes in the physical and chemical properties of the soil [30]. In other words, there was an interdependent and restrictive relationship between vegetation and the soil [71].

5. Conclusions

The slope provides a heterogeneous habitat for the plant community and affects the soil development. Continuous slope gradient is an important factor affecting plant communities in alpine meadows. Plant community characteristics and the physical and chemical properties of the soil varied significantly at each slope gradient level. In our study, the main conclusions were as follows: (1) Slope is the main factor that affects plant species composition, soil and water conditions in alpine meadows, directly or indirectly, by changing ecological factors, such as partial moisture, and the physical and chemical characteristics of the soil; (2) the dominance values of dominant species are small and show fluctuations; (3) different plant functional groups and plant diversity have irregularities, which reflects

that the plant community characteristics are affected by many factors; and (4) the physical and chemical properties of soil continually changes. Furthermore, there was a close relationship between the soil and plant functional groups, and plant diversity. In addition, pH value (pH), Soil Total Nitrogen (STN) and Soil Water Content (SWC) were determining factors of plant community characteristics at each slope gradient level.

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