

Responses of Alpine Grassland Plant Functional Groups To Environmental Changes In The Altunshan At North Qinghai-Tibet Plateau

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Abstract

Purpose: In grassland ecosystems, plant functional group (PFG) is an important bridge connecting individual plant to community system. Grassland ecosystem is the main ecosystem type on the Qinghai-Tibet Plateau, so the change of community structure of grassland vegetation.

Methods: The Altun Mountains in the northern part of the Qinghai-Tibet Plateau were used as the study area to investigate the PFGs of a high-altitude (> 3700m) grassland in desert areas and their response to temperature and moisture.

Results: The main functional groups were forbs and grasses, and the importance values (IV) accounted for more than 50%. Plant species diversity of the community was influenced by the functional groups of legumes IV, and the increase of legumes would promote the increase of plant community diversity. The C, N, P of plant communities were mainly influenced by forbs and grasses, and the relationship between forbs and C, N, P was opposite to that of grasses. There was a positive correlation between forbs and soil TP; a negative correlation between grasses and soil TP; a positive correlation between legumes with soil SOC and TN; and a positive correlation between sedge and soil SOC. However, under the influence of different hydrothermal conditions, forbs and grasses as dominant functional groups had stronger correlation with community and soil nutrients.

Conclusions: This indicated that the PFGs with the largest proportion in the community had the greatest influence on the community. This provides a basis for the study of alpine grassland community development and ecosystem function under alpine grassland.

1. Introduction

Grassland ecosystem is an important terrestrial ecosystem, and it is an important transitional zone in the arid and semi-arid regions (Dong et al., 2010). With the intensification of global climate change and human activities, the community composition of grassland ecosystem has changed significantly (Li et al., 2000). In order to better summarize and analyze the vegetation changes in grassland communities, classifying plants with similar attributes into groups called plant Functional Groups (PFGs) (Solbrig et al., 1993). PFG connects individual plant traits and community ecological processes, and is an important method for classification of species (Eviner and Chapin, 2003). PFGs acts as an assemblage of similar species can connect ecosystem and species, establish a direct relationship between vegetation and climate, and make comparisons at different regional scales (Skarpe, 1996; Lavorel et al., 1997).

In grassland ecosystems, herbaceous plants have a short life cycle and are highly responsive to the environment, so PFG is very sensitive to vegetation types, soil factors and climate changes. At the same time, some changes in PFGs also represent changes in a community. Previous studies have shown that the change in some dominant species of a community will have a great impact on the plant community composition (Hooper and Vitousek, 1997). The effects of PFGs on community structure and function are mainly due to the ecological strategies of different species in response to environmental changes. Meta-

analyses (Cardinale et al., 2006) have shown that changes in species richness can alter ecosystem functions, and different functional groups have different effects on species richness in many studies (Fischer et al., 2015). In addition, PFG plays a key role in determining the impact of species loss on ecosystems (Mclaren and Turkington, 2010). In previous studies of grassland ecosystems, removal treatments showed that the loss of grasses had a greater impact on the plant community than the loss of other functional groups, such as legumes, which could not compensate for the loss of grasses in the arid meadows of northern Canada (Mclaren and Turkington, 2010). Mowing the whole community also increased the community diversity and changed the composition of PFGs (Fynn, 2004). In addition, studies have shown that the increase of soil nitrogen (N) content and the high content of soil phosphorus (P) will decrease the community diversity (Baer et al., 2003; Kattge et al., 2011), and affect the composition of PFGs by changing the dominant functional group (Li et al., 2020). Soil nutrients not only affect the composition of PFGs, but also receive negative feedback from the change of PFGs. The effects of different functional groups on soil nutrients were mainly caused through altering litter quantity, amount of root exudates, and intensity of resource utilization (Porazinska et al., 2003). The changes in PFGs may modulate the response of soil carbon (C) to long-term global climate changes (Du et al., 2018).

In extreme cold or dry environments, composition and ecological strategies of PFG for coping with the extreme environment differ from those of other ecosystems with mild environmental conditions. A study has pointed out that herbs invest preferentially in structures for persistence (K-strategy) in the alpine grasslands (Patty et al., 2010). Therefore, different PFGs have contrasting adaptations in alpine or arid environments. Studies have shown that with the degradation of alpine grasslands, the density per unit area of vascular plants, grasses and sedges, decreased on the Qinghai-Tibet Plateau (Yang et al., 2013). In the arid environments, the biomass allocation of PFGs was different in response to the stress caused by the arid environment (Carlsson et al., 2017). Drought would decrease the PFG of legumes and increase the functional group of grasses (Stampfli et al., 2018). At the same time, changes in PFGs can also affect the environment through modifying the water cycle (Wu et al., 2019). For example, because of the difference in root biomass, leguminous functional groups can increase the surface soil water content, while grass functional groups can decrease the surface soil water content (Ravenek et al., 2014). But in cold environments at high altitudes, plant functional groups are more likely to be affected by soil nutrient accumulation (Dormann and Woodin, 2002).

The alpine grassland is the main vegetation type on the Qinghai-Tibet Plateau, which not only maintains the plateau ecosystem and production, but also has an important impact on the ecological security of the downstream region (Cao et al., 2014). The Altyn Tagh lies to the north of the Qinghai-Tibet Plateau, the natural climate features are cold and dry, and belonging to the Qinghai-Tibet Plateau cold climate. The first alpine desert nature reserve was established here in the world, and it plays an important role in the protection of alpine desert ecosystems and their unique species (Wei et al., 2016). The vegetation types are different from those of other grassland ecosystems in the Altun Mountains. In the low altitude, the alpine desert vegetation is the main vegetation type, and in the high altitude, the vegetation types are composed of alpine desert and alpine grassland (Wei et al., 2016). Therefore, community composition and functional groups are more abundant at higher altitudes than at lower altitudes. In the extreme

environment at high altitude in the Altun Mountains in the northern part of the Qinghai-Tibet Plateau, we put forward the question that how PFGs are affected by environmental factors? Therefore, the aims of this study are: 1) response strategies of the same PFG to environmental change are different across ecosystems; 2) PFG composition of alpine desert ecosystem is more sensitive to environmental conditions as compared with other vegetation types; 3) forbs plants are more adaptable to extreme environments than other functional groups due to their rapid adaptation to the environment.

2. Methods And Materials

2.1 Study site and Experimental design

Altunshan Nature Reserve is located in the south of Altyn Tagh and the north of Qinghai-Tibet Plateau (87°10'E - 91°18'E, 36°N - 37°49'N). The study area belongs to the plateau climate, the climate is dry and cold. The mean annual temperature is about 0°C and annual rainfall is about 300 mm, the sunshine intensity is high. The soils are mainly developed from alpine desert soil, alpine steppe soil and high mountain desert soil, some areas also have alpine meadow soil. The Reserve is rich in vegetation types, mainly include deserts, grasslands, marsh e.g. The height of grasses layer is mostly 5 - 20 cm, the coverage is 10% - 30%, and the coverage can reach 60% - 80% in some alpine grassland. The dominant species include *Stipa purpurea* and *Kobresia robusta*, common companion species is *Carex kunlumsannsis*, *Koeleria cristata*, *Oxytropis falcata* e.g. (Wu et al., 2013).

In August 2019, we carried out the field survey and a total of 9 representative plots were randomly selected in the Altunshan Natural Reserve. The altitude of all the samples was higher than 3700m (A 1 - 3720 m, A 2 - 3790 m, A 3 - 3740 m, A 4 - 3720 m, A 5 - 3715 m, A 6 - 3730 m, A 7 - 3740 m, A 8 - 3745 m, A 9 - 3790 m) and the vegetation type belonged to alpine grassland (Fig. 1). Each plot records its geographical location, including latitude and longitude, altitude, slope, e.g. According to the field conditions, a total of 5 quadrates (100 cm x 100 cm) were arranged in each quadrat line, and the coverage frequency and height of plant species in each quadrat were investigated and recorded. The cover of different functional groups and the community were summed up by the per species coverages. From the estimates of canopy coverage per species, we determined the relative coverage of each and entire community (i.e. percent cover). And the dominance of plant species was calculated. Then, all plants were cut from the ground in the quadrat, their fresh weight was respectively recorded, and their weight was called after drying. Upon completion of above-ground sample collection, the soil samples were collected from 0 to 5 cm, 5 to 10 cm, 10 to 20 cm, and 20 to 40 cm with 7 cm drills in the same quadrates. And plants root isolated from the soil samples, their weight was called after drying. According to plant traits, all sample sites were divided into four plant functional groups (PFGs): forbs, grasses, legumes and sedge.

2.2 Soil and plant laboratory measurements

After completing a field survey and sampling, Plant samples (aboveground and root samples) were placed in the oven at 105°C for 30 min, then oven-dried at 75°C for 48 hr weighed the biomass thereafter. All soil samples were measured at sampling conditions (wet weight) and soon after oven-dried for 48 h at 105°C and then weighed again. Soil pH was determined using a conductometer (1:1 soil-water suspension) and acidimeter (1:5 soil-water suspension). Soil organic carbon (SOC) was determined using the $K_2Cr_2O_7$ oxidation. Soil total nitrogen (TN) was determined using Vario Macro Cube - Elemental Analyzer. And soil total phosphorus (TP) concentrations were determined using H_2SO_4 - $HClO_4$ digestion methods. The plant samples were determined for SOC, TN, TP after drying 48 hr at 75°C, and the determination method is the same as that of soil samples.

2.3 Data processing

2.3.1 Importance values

The importance value (IV) of a species can be regarded as the dominance of each species in the community, reflecting the influence of that species in the community (Whittaker and Niering, 1965). The IVs of different vegetation types are obtained through different calculation methods (Qian et al., 2008). The IV of plant functional groups are composed of the IV of the species that make up the plant functional group.

The IV was calculated this way:

$$IV = (C+H+F)/3$$

where C denotes the relative coverage, this given by the coverage of a species in the sample plot divided by the coverage of all species in that same plot; the H denotes the relative height, it being the height of a species in the sample plot divided by the height of all species in that same plot; the F denotes the relative frequency, it being the frequency of a species in the sample plot divided by the frequency of all species (Yang, 2009).

2.3.2 α -diversity indexes

With an increase of altitude along the gradient, environmental factors such as temperature and precipitation are bound to change. This leads to alterations in community structure, species diversity, and species composition. To convey these changes, well-established diversity indexes were used here to represent species richness, evenness, dominance, community structure, and spatial heterogeneity (Whittaker and Niering, 1965; Zhang et al., 2018). We calculated them based on the species data obtained from the vegetation survey; the four specific indexes derived were as follows:

(1) Patrick richness index (R)

$$R = S$$

(2) Shannon-Wiener index (H')

$$H' = -\sum P_i \ln P_i$$

(3) Simpson index (D)

$$D = 1/\sum P_i^2$$

(4) Pielou evenness index (Jsw)

$$Jsw = H/\ln S$$

In these equations, S denotes the total number of species in a plot; P_i indicates the relative IV of the i th species; S' is the average species number of the quadrat of the plot; H' represents the number of existing species in the plot and the relative abundance of each species; D is the dominance of a given species in the community. Jws represents the distribution of all species within the community (Hill, 1973).

2.3.3 Data analysis

One-way ANOVAs and the least significant difference (LSD) test were used to analyze the differences in diversity of species (R , H' , D , Jsw), followed by Duncan's test. Pearson's correlation analysis was used to test relationship of PFGs importance values, biomass (above-ground biomass, root biomass), diversity (R , H' , D , Jsw), plant nutrients (SOC, TN, TP) and physical and chemical properties of soil (SOC, TN, TP, pH, soil moisture).

In the alpine grassland ecosystem, the changes of PFGs are affected by several environmental variables. The multiple linear regression model (MLR) is a method for modeling the linear relationship between predicted variable and more predictors by fitting linear equation to the model (Bashir et al., 2019). Therefore, we carried out multiple linear regression model (MLR) analysis on different PFGs and nutrients, biomass, diversity and other factors in the community, as follows:

$$(5) Y = T + T_1 X_1 + T_2 X_2 + T_3 X_3 + \dots$$

In these equations, Y is the value for the parameters of the PFGs, and T_n is the value for each corresponding environmental variable (Kutner and Nachts, 2005). All statistical analyses were implemented within SPSS 22.0, Origin 9.3 and R 3.6.2.

3. Results

3.1 PFG importance values of different communities

A total of 22 species were identified from all the sample sites, which were divided into four plant functional groups (PFGs) according to their traits, including forbs, grasses, legumes and sedge. The community of the ecosystem is mainly composed of forbs and grasses, and forbs and grasses accounted for more than 50% of the community importance values in all the samples investigated (Fig.

2). The percentage of importance values of legumes and sedges was relatively low, and only existed in a few sample sites (A 1, A 2, A 5, A 9) (Fig. 2). In the correlation analysis with biomass, there was significant positive correlation between forbs with aboveground and underground biomass ($p < 0.05$), and extremely significant positive correlation with total biomass ($p < 0.001$) (Table 1). There was a significant negative correlation between grasses with underground biomass ($p < 0.001$) (Table 1). But there was no significant correlation between legumes and sedges with community biomass.

Table 1
Correlation analysis of plant functional group importance values and biomass. The * indicates a significant correlation ($p < 0.05$), the ** indicates extremely significant correlation ($p < 0.001$).

	<i>Forbs</i>	<i>Grass</i>	<i>Legume</i>	<i>Sedge</i>
Above-ground biomass (g)	0.342*	-0.218	-0.140	-0.054
Under-ground biomass(g)	0.368*	-0.401**	-0.153	-0.001
Total biomass (g)	0.386**	-0.279	-0.158	-0.050
Under/Above biomass	-0.253	-0.081	-0.030	-0.028

3.2 PFG and community level diversity analysis

The results show that the diversity of plant communities at the same altitude was not consistent. Shannon-wiener index was significantly higher than other sample points in A 1 and A 2, but Simpson index was opposite to Shannon-wiener index, A 1 and A 2 were significantly lower than other sample points (Table 2). Pielou Evenness index and Richness index changed more dramatically, but the indexes in A 1 and A 2 were also significantly higher than other sample points (Table 2). In the correlation analysis between diversity and PFGs, only legumes were significantly correlated with diversity indices (Fig. 3). There was a significant positive correlation between Shannon-wiener, Pielou Evenness, Richness and legumes functional group, and a significant negative correlation between Simpson and legumes. But there was no significant correlation between other functional groups (Forbs, Grass, Sedge) and diversity indexes (Fig. 3).

Table 2

Changes of different diversity indicators. Within a column, significant differences between means (\pm SE, $n = 5$) are indicated by different letters (post-hoc Tukey's HSD test, $P < 0.05$).

	Shannon-wiener	Simpson	Pielou Evenness	Richness
A1	1.09 \pm 0.42 ^b	0.61 \pm 0.16 ^a	0.91 \pm 0.08 ^d	3.60 \pm 1.52 ^d
A2	1.42 \pm 0.39 ^c	0.70 \pm 0.16 ^a	0.85 \pm 0.10 ^d	5.40 \pm 1.67 ^e
A3	0.28 \pm 0.07 ^a	0.95 \pm 0.06 ^b	0 ^a	1.00 ^a
A4	0.31 \pm 0.11 ^a	0.98 \pm 0.01 ^b	0.24 \pm 0.33 ^b	1.40 \pm 0.55 ^{ab}
A5	0.49 \pm 0.07 ^a	0.96 \pm 0.02 ^b	0.49 \pm 0.10 ^c	2.80 \pm 0.45 ^{cd}
A6	0.25 \pm 0.13 ^a	0.99 \pm 0.01 ^b	0.31 \pm 0.20 ^{bc}	2.40 \pm 0.55 ^{bcd}
A7	0.27 \pm 0.15 ^a	0.99 \pm 0.01 ^b	0.25 \pm 0.24 ^b	1.80 \pm 0.84 ^{abc}
A8	0.30 \pm 0.22 ^a	0.99 \pm 0.02 ^b	0.34 \pm 0.16 ^{bc}	2.40 \pm 0.89 ^{cd}
A9	0.28 \pm 0.05 ^a	1.00 \pm 0.001 ^b	0.28 \pm 0.07 ^{bc}	2.80 \pm 0.45 ^{bcd}
a, b, c, d Values with different superscripts are significantly different between and/or among the response variables within column.				

3.3 PFGs and analysis of plant and soil C, N, P

The results show that there was a significant negative correlation between forbs and community plant P, and grasses, legume and community plant P showed significant negative correlation. Sedge was positively correlated with community plant C (Fig. 4a). But both forbs and grasses were significantly correlated with underground root nutrients. Forbs was positively correlated with C and N in underground root, and negative correlated with P in underground root; Forbs was negative correlated with C and N in underground root, and positively correlated with P in underground root; and legume was only positively correlated with P in underground root (Fig. 4a). In addition, among the four functional groups in the study area, the sum of correlation coefficients of forb and grass was greater than that of legume and sedge, and was more strongly correlated with C, N and P of the plant community (Fig. 4b). At the same time, forbs were negative correlated with grasses. In the correlation analysis between PFGs and soil physical and chemical properties, the results showed different correlations with plant nutrients. Forbs was positively correlated with soil TP, and grasses was negative correlated with soil TP (Table 3). In addition, legume was positively correlated with soil SOC and soil TN; sedge was positively correlated with soil SOC and soil moisture (Table 3).

Table 3

Correlation analysis of PFGs and soil physical and chemical index. The * indicates a significant correlation ($p < 0.05$), the ** indicates extremely significant correlation ($p < 0.001$).

	<i>Forbs</i>	<i>Grass</i>	<i>Legume</i>	<i>Sedge</i>
SOC	-0.202	-0.013	0.540**	0.409**
TN	-0.113	-0.054	0.545**	0.281
TP	0.600**	-0.586**	0.152	-0.216
pH	-0.183	0.214	-0.208	-0.084
Soil moisture	-0.205	0.010	-0.221	0.420**

3.4 Multivariate linear regression (MLR) analysis of functional groups and related influencing factors

We performed multiple linear regression (MLR) on the main functional groups (Forbs and Grass) of all the sample sites. The results show that the forb was mainly affected by the under/above biomass ($p < 0.001$), community plant N ($p = 0.044$) and underground root N concentration ($p = 0.018$). Under/above biomass and community plant N had negative effects on forbs, while underground root N had positive effects on forbs (Table 4a; Fig. 5a). The multiple linear regression model of forbs is (1). Among them, underground root N contributed the most to forbs (T_{17} normalized coefficient is 0.652). The grass was mainly affected by soil TP ($p = 0.012$), water moisture ($p = 0.022$), community TN ($p = 0.011$) and community TP ($p = 0.041$). The soil TP, water moisture, and community plant P had negative effects on grasses, while community plant N had positive effects on grasses (Table 4b; Fig. 5b). The multiple linear regression model of grass is (2). Among them, soil TP contributed the most to grasses (T_{10} normalized coefficient is -0.884).

$$Y = -0.408X_1 - 0.29X_2 + 0.652X_3 \quad (1)$$

$$Y = -0.884X_1 - 0.573X_2 + 0.469X_3 - 0.672X_4 \quad (2)$$

Table 4 Statistical results of multiple linear regression parameters ($p < 0.05$)

(a)

<i>Forbs</i>	Index	Nonstandardized coefficient	Normalized coefficient	T	<i>p</i>	VIF
T	Constant	105.178		1.244	0.225	
T ₁	Shannon	18.694	0.329	0.738	0.467	27.532
T ₂	Simpson	35.461	0.215	1.072	0.294	5.571
T ₃	Pielou	-2.153	-0.027	-0.135	0.894	5.467
T ₄	Richness	-1.575	-0.091	-0.276	0.785	15.099
T ₅	Above-ground biomass	0.033	0.06	0.517	0.609	1.864
T ₆	Root biomass	0.153	0.06	0.413	0.683	2.918
T ₇	Under/Above biomass	-6.04	-0.408	-4.082	0.000	1.393
T ₈	Soil SOC	-7.777	-0.573	-1.168	0.253	33.411
T ₉	Soil TN	33.193	0.271	0.556	0.583	32.968
T ₁₀	Soil TP	86.515	0.293	1.13	0.269	9.387
T ₁₁	pH	-13.247	-0.217	-1.423	0.167	3.22
T ₁₂	Water moisture	1.36	0.291	1.551	0.133	4.904
T ₁₃	Plant C	-0.082	-0.15	-1.333	0.194	1.772
T ₁₄	Plant N	-1.767	-0.29	-2.119	0.044	2.598
T ₁₅	Plant P	21.231	0.382	1.53	0.138	8.676
T ₁₆	Root C	-0.042	-0.121	-0.435	0.667	10.742
T ₁₇	Root N	6.278	0.652	2.531	0.018	9.237
T ₁₈	Root P	-61.489	-0.315	-1.661	0.109	5.006
DW = 2.262						

(b)

Grass	Index	Nonstandardized coefficient	Normalized coefficient	T	<i>p</i>	VIF
T	Constant	-58.171		-0.508	0.615	
T ₁	Shannon	16.928	0.276	0.494	0.625	27.532
T ₂	Simpson	-74.852	-0.419	-1.672	0.107	5.571
T ₃	Pielou	21.181	0.244	0.98	0.336	5.467
T ₄	Richness	-3.764	-0.201	-0.487	0.631	15.099
T ₅	Above-ground biomass	-0.086	-0.146	-1.008	0.323	1.864
T ₆	Root biomass	0.071	0.026	0.143	0.888	2.918
T ₇	Under/Above biomass	0.052	0.003	0.026	0.979	1.393
T ₈	Soil SOC	-0.28	-0.019	-0.031	0.975	33.411
T ₉	Soil TN	-42.611	-0.322	-0.527	0.602	32.968
T ₁₀	Soil TP	-281.489	-0.884	-2.715	0.012	9.387
T ₁₁	pH	24.362	0.369	1.933	0.064	3.22
T ₁₂	Water moisture	-2.89	-0.573	-2.434	0.022	4.904
T ₁₃	Plant C	0.103	0.176	1.243	0.225	1.772
T ₁₄	Plant N	3.087	0.469	2.735	0.011	2.598
T ₁₅	Plant P	-40.34	-0.672	-2.147	0.041	8.676
T ₁₆	Root C	0.114	0.307	0.88	0.387	10.742
T ₁₇	Root N	-5.598	-0.539	-1.668	0.107	9.237
T ₁₈	Root P	49.489	0.235	0.987	0.333	5.006
DW = 2.165						

4. Discussion

In our study, PFGs responded differently to environmental changes and community competition. In this study area, the climate is dry and cold (Fig. 1), so the dominant functional groups of the community are grasses and forbs (Fig. 2). This is mainly because the forbs are the main dominant PFGs in the desert

area and has strong adaptability to the arid environments (Ning et al., 2017). On the other hand, grasses have a conservative resource-use strategies and are strongly cold-tolerant, so they can adapt well to high altitude environment (Suding et al., 2015). This is also consistent with the finding from other study area of the central Tibetan Plateau at the same altitude, where the grassland vegetation types are dominated by grasses (Niu et al., 2019). At the same time, previous studies have shown that the growth of legumes will consume more water, and legumes could not survive in nutrient-poor desert areas, especially mobile dunes (Guo et al., 2017; Cui et al., 2018). Therefore, in this study area, the dominant functional group of each sample site was forbs or grasses, and the importance value of both reached more than 50% of the community. The mass ratio hypothesis predicts that the species with the greatest proportion in the community will have the greatest impact on the ecological function of the community (Grime, 1998). In this study, forbs fit this hypothesis and have significant correlation with community biomass; however, the grasses, legume and sedge did not fit the hypothesis, and the increase of grass functional groups only affected the root biomass of the community (Table 1). The main reason is that grass function group allocates less photosynthate to roots than to aboveground organs in alpine regions (Wu et al., 2013). The results indicated that the forbs had a dominant influence on the community in this area. This was different from the previous functional group removal experiments in arid northern grassland of Canada, in which the effect of grasses functional group on community biomass was dominant (McClaren and Turkington, 2010).

In addition to community biomass, PFGs are also related to community species diversity. Within the study area, species diversity, richness and evenness of the community were significantly affected by legumes (Fig. 3). The results indicated that the legumes functional groups reflected the community succession and development in the alpine grassland communities with forbs and grasses as dominant functional groups (Hu et al., 2016). In addition, the dominant functional groups determined the community structure, but could not reflect the development trend of the community. In other words, if a plant community is dominated by a few functional groups, then differences in species composition will have a greater impact on the whole system (Hooper and Vitousek, 1997). Therefore, the discovery of legumes functional groups has a large effect on the prediction and discovery of ecosystem functioning in degraded grassland and extreme climate zones (Spehn et al., 2002; Scherer-Lorenzen et al., 2003). However, in previous studies in arid areas, legumes could not survive in nutrient-poor areas (Guo et al., 2017), so the changes of different PFGs in the community were related to nutrients.

Soil nutrients are the basis of plant growth, and the allocation of plant nutrients reflects the ecological strategies of plants to cope with environmental changes (Elser, et al., 2010; Craine and Dybzinski, 2013). In this study area, forbs and grasses were the main components of plant communities, so the P concentration of plant communities and the C, N, P concentration of underground roots were mainly related to the functional groups of forbs and grasses (Fig. 4). This is mainly because plants spend more resources to roots in less diverse and resource-poor environments, which is consistent with the alpine grassland ecological strategy of invest preferentially in structures for persistence (K-strategy) in previous studies (Patty et al., 2010; Ning et al., 2021). The legume functional group, as the key functional group affecting community diversity, was only significantly correlated with P in the community (Fig. 4). Studies

have shown that legume are important species affecting plant community diversity. These results indicated that P content was an important factor limiting grassland species diversity (Kattge et al., 2011). Nutrient limitation affects the composition of community functional groups and response strategies to environmental change. The study area is located at a high altitude of more than 3700m, where the climate is dry and the soil nutrient content is low. In all the communities we studied, grass and forb were significantly correlated with soil P concentration (Table 3), and as dominant functional groups, grass and forb had important effects on community composition. These results indicated that soil P content was the main limiting factor affecting the plant community construction and the changes of main functional groups in this study area. This is consistent with previous studies that plant growth on the Qinghai-Tibet Plateau is mainly restricted by soil N and P, and the availability of N and P nutrients has an important effect on species composition and community structure (Janssens et al., 1998; Nie et al., 2010). The functional groups of legumes affected the contents of C and N in soil, the changes of nitrogen fixation and community composition affected the absorption and transformation of C and N in soil. (Hooper and Vitousek, 1998; Spehn et al., 2002). In the alpine desert grassland, the increase of legumes function group not only affected the diversity of community species, but also reduced the loss of soil C and N (Wen et al., 2013; Wu et al., 2018). The results indicated that different plant functional groups would adapt to the changes of external environment according to their own traits under the same resource environment. In addition to soil nutrient, soil moisture is also one of the important factors affecting plant growth (Angers and Caron, 1998; Xu et al., 2018). However, in our study, only sedge function group and soil moisture had significant correlation, while the major functional groups (forbs and grass) in the community showed no response to soil moisture (Table 3). The results indicated that functional groups such as grasses and forbs were less dependent on soil moisture than legumes and sedges (Cui et al., 2018). This is consistent with the previous researches that the increasing functional groups of forbs and grasses in arid areas can reduce the consumption of soil water and have a strong adaptability to arid habitats (Wu et al., 2019). These studies suggest that the desert PFGs can maintain a high utilization efficiency for soil nutrients under resource-limited conditions as a result of the function group's plasticity and ability to adapt to extreme environment (Aerts and Chapin, 1999; Berendse and Aerts, 1987).

As an indicator of changes from species to community level, PFGs are effective tools for biomass allocation, diversity change and community composition (Wu et al., 2013; Bora et al., 2020). Changes in PFG tend not to be influenced by a single factor, but by multiple factors, such as rainfall patterns, elevation gradients, nutrient availability, and atmospheric CO₂ (Cramer et al., 2001; Weltzin et al., 2003). In this study, grasses and forbs, as dominant functional groups, were strongly responsive to a number of abiotic factors (Table 4; Fig. 5). There was a strong direct correlation between grasses and forbs with community nutrients (N and P). In the analysis of the functional of forbs, the aboveground community N concentration had a negative effect, while the underground root N concentration had a positive effect, but the results for grasses were the opposite of those for forbs (Table 4; Fig. 5). This is mainly because most grasses have highly branched fibrous root systems than forbs plants and can absorb nutrients in the surface soil more efficiently (Chapin et al., 1995; You et al., 2017). Therefore, the forbs allocate more nutrients to the root system to sustain growth, while the grasses allocate more nutrients to the growth of

above-ground organs. This indicates that the plant community construction in this study area is mainly affected by soil N content, which is consistent with the current studies that the Qinghai-Tibet Plateau is mainly affected by N and P in previous studies (Nie et al., 2010). In addition, grasses had negative effects on soil moisture and soil TP while being affected by N content (Table 4 b; Fig. 5 b). These results indicate that grasses have more competitive advantages over the forbs due to their conservative resource-use strategies in extreme environments (Suding et al., 2005). This is inconsistent with our third hypothesis.

Conclusion

In the alpine desert grassland, the species composition of PFGs is relatively small, and different functional groups have different adaptability to the environment. In our study, the grass and the forb groups were the dominant functional groups in the study area, which had a great influence on the composition and structure of the community. Grass and forb groups adapted to environmental changes through allocation of biomass and nutrients. However, the increase of legume groups can significantly improve the diversity and stability of the community. Due to the differences in the characteristics of functional groups and their roles in the community, different PFGs had different responses to C, N, P in soil and community. At the same time, the grass group have stronger adaptability than other plant functional groups under extreme environment. Overall, PFGs are the important factor affecting the composition and structure of a community. The composition and change of different PFGs can reflect the change and succession direction of a community.

Declarations

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Figures

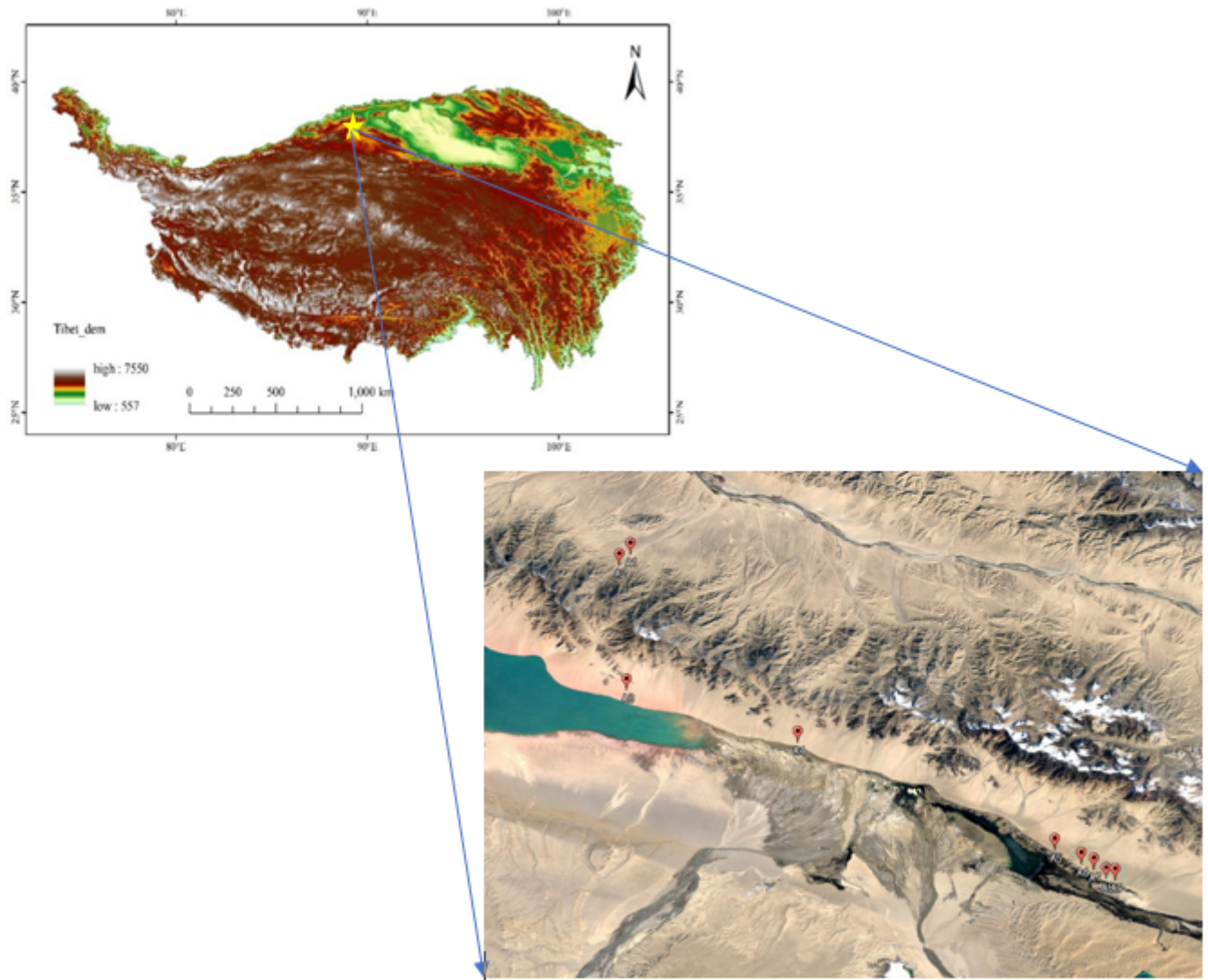


Figure 1

Distribution of sample points

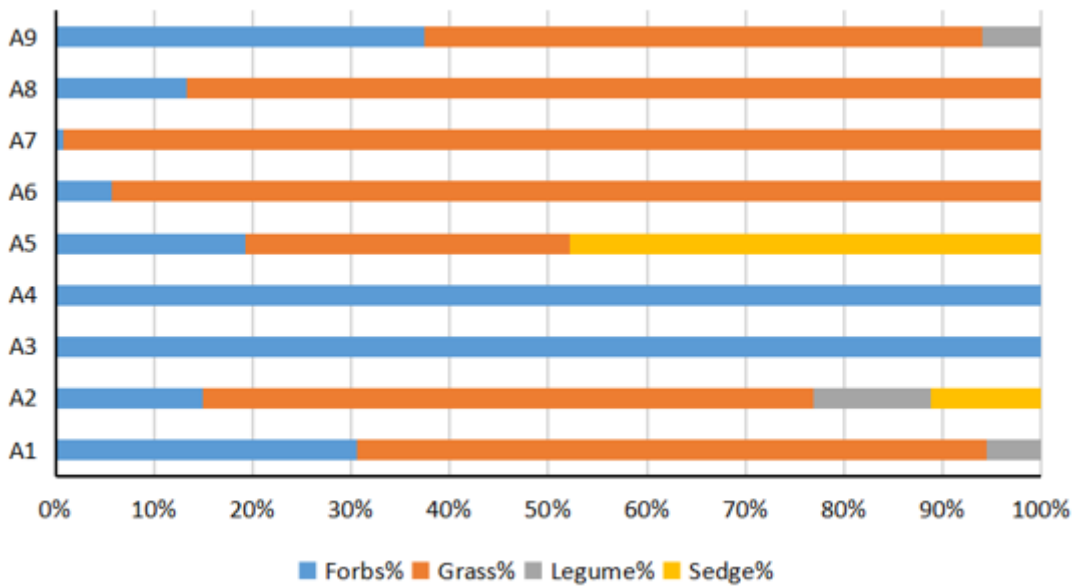


Figure 2

Percentage of important values of different plant function groups

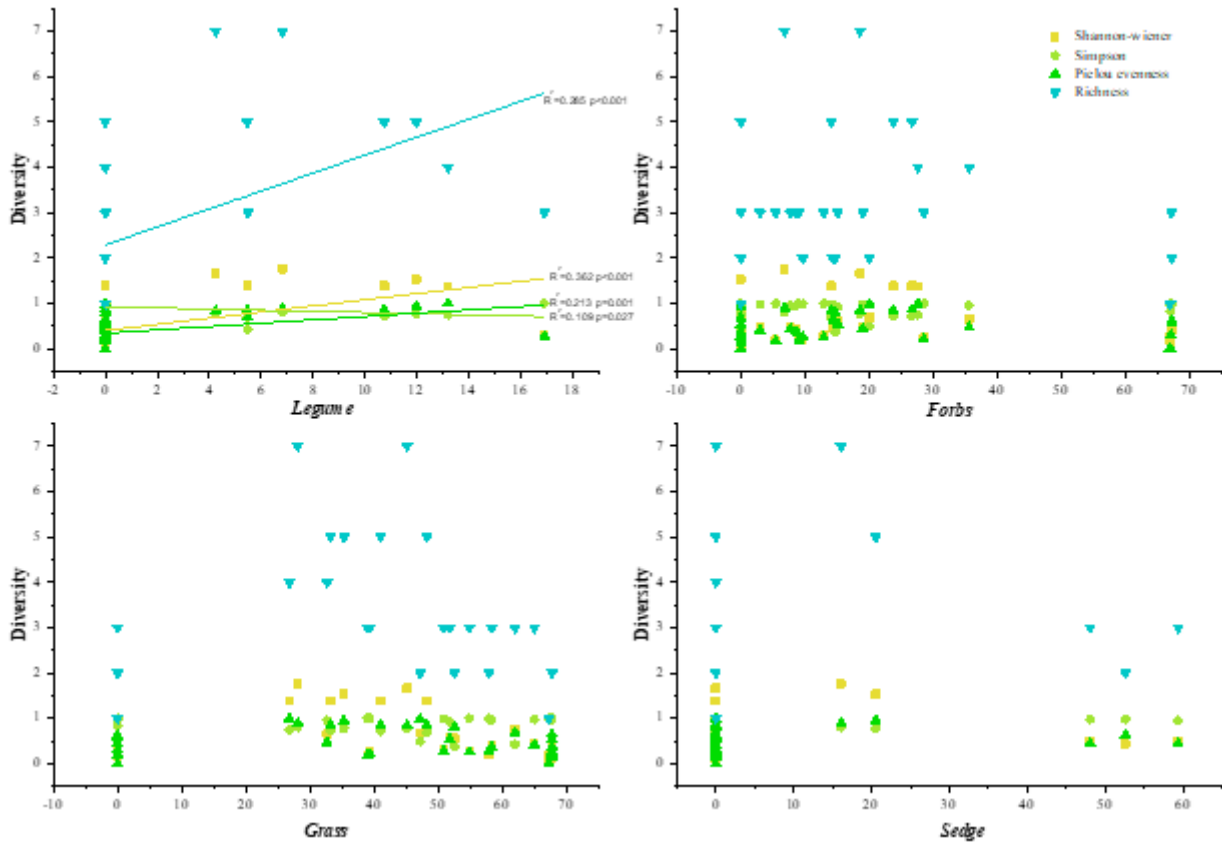


Figure 3

Relationships between PFGs and diversity. The solid line indicates a significant correlation ($p < 0.05$).

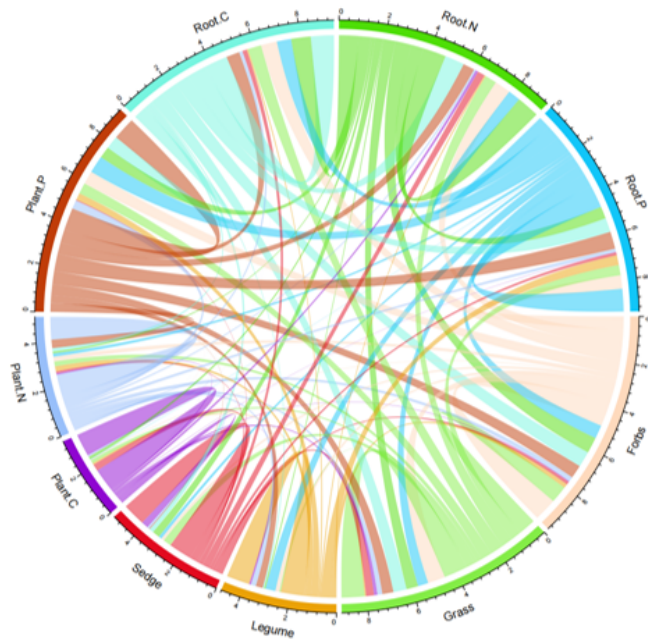
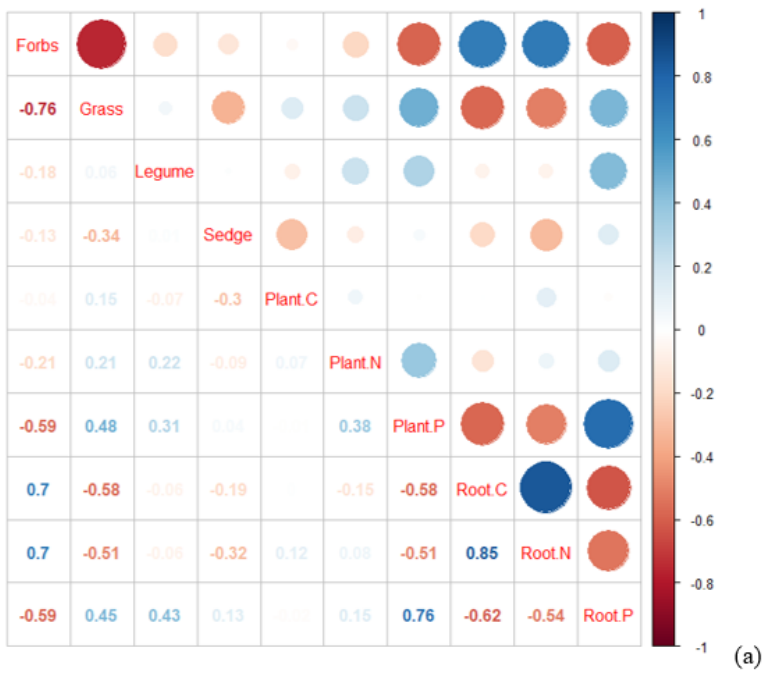


Figure 4

Correlations between PFGs with plant C, N, P and root C, N, P. The asterisk * indicates significant correlations at the $p < 0.05$ level.

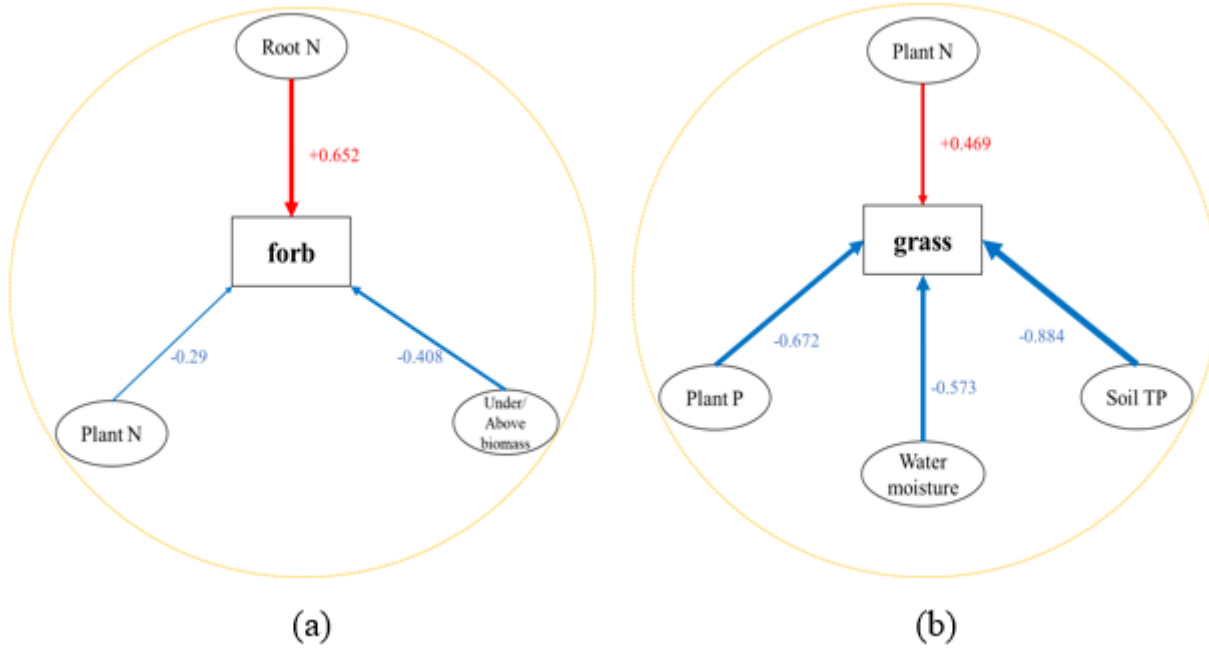


Figure 5

Schematic diagram of the relationship between forb and grass and different environmental factors. The blue arrow represents the negative effect and the red arrow represents the positive effect.