Eurasian J Soil Sci 2015, 4 (2) 88 - 93

Eurasian Journal of Soil Science

Journal homepage : http://fesss.org/eurasian_journal_of_soil_science.asp

The relationship between soil physical properties and alpine plant diversity on Qinghai-Tibet Plateau

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Article Info

Received : 15.07.2014
Accepted : 28.12.2014

Abstract

Through a large-scale research, we examined the heterogeneity of soil properties and plant diversity, as well as their relationships across alpine grassland types on Qinghai-Tibet Plateau. The soil pH and EC value increased with the constant deepening of the soil in all the three alpine grassland types which in order of absolute value in every soil layer were alpine desert steppe, alpine steppe and alpine meadow. Among the three grassland types, the alpine meadow possessed the highest SM but the lowest SBD. For plant diversity, alpine meadow was the highest, alpine desert steppe ranked the second and alpine steppe was the last. SM and SBD were the highest influential soil physical properties to species richness, but with opposite effects.

Keywords: Alpine grassland, plant diversity, soil physical property

Introduction

+ÎÏ×Î ÁÓ ȮÔÈÅ ÒÏÏÆ ÏÆ ÔÈÅ ×ÏÒÌÄȭ ÁÎÄ ȮÔÈÅ ÔÈÉÒÄ ÐÏÌÅȭȟ ÔÈÅ 1ÉÎÇÈÁÉ-4ÉÂÅÔ 0ÌÁÔÅÁÕ ɉ140Ɋ ÉÓ ÔÈÅ ×ÏÒÌÄȭÓ ÈÉÇÈÅÓÔ and largest plateau. The diverse climate and complex terrain and topography create a highly heterogeneous environment supporting a large diversity of plants and animals and is regarded as a global biodiversity hotspot containing the largest pool of alpine biodiversity in the World (Dong et al. 2010). There are large-scale longitudinal, latitudinal and altitudinal climatic gradients that divide the plateau into vegetation zones; forests and shrubs occur in the wet and warm southeastern and eastern margins of the plateau, alpine meadows in the vast areas of eastern and south-eastern Plateau, temperate and alpine steppe in the north-eastern and central plateau, and alpine desert in the dry north-central and north-western Plateau.

Overall, alpine ecosystems on the Qinghai-Tibet Plateau have a unique ecological structure, where soil is the key ecological factor controlling ecological processes (Yang et al. 2011). Plants and soil are interdependent, and each can be affected by alterations in the other (Silva and Batalha, 2008). Plant community cannot be separated from the dynamics of soil parameters, and different soils with different chemical, physical and microbiological properties vary vegetation distribution and diversity (Eskelinen et al. 2009). So far, numerous researches have been conducted to examine the relationship between soil factor and plant diversity on Qinghai-Tibet Plateau, and the results indicated that soil differentiation was strongly correlated to vegetation cover, grass biomass, plant diversity and other community characteristics (Ren et al. 2013; Wang et al. 2012; Wen et al. 2011; Zhou et al. 2004). However, most of the researches were on controlled trial level or at small site scale, so it is hard to expand the results to the natural and broad alpine grassland

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ISSN: 2147-4249

ecosystem. In this study, we conducted a large-scale study across different grassland landscapes of the QTP to understand the effects of soil properties, especially physical properties on alpine plant diversity.

Material and Methods

Study Area

The Qinghai-Tibet Plateau (QTP) is located in western China covering an area of 2.5 million km2. It serves as the headwater area for several major Asian rivers, such as the Ganges, Indus, Yangtze, Yellow, Mekong and 3ÁÌ×ÅÅÎ ÒÉÖÅÒÓñ ÁÎÄ ÒÈÉÓ ÉÓ ËÎÏ×Î ÁÓ ÒÈÅ 7ÁÔÅÒ 4Ï×ÅÒ ÏÆ !ÓÉÁ (Wang and Cheng, 2001). Alpine grasslands are the dominant vegetation of the QTP, covering approximately 1.63 million km2 of the area (Qin et al. 2014). They are not only habitats for endemic alpine plants and animals, but also important grazing pastures for the mostly Tibet indigenous people who live on the QTP. As an important ecosystem services provider and a significant role in climate change (Li et al. 2013; Zhang et al. 2006), Qinghai-Tibet Plateau alpine ecosystem especially the alpine grassland, alpine meadow, alpine steppe and alpine desert steppe, three main types of vegetation, have become the hotspot of ecological study.

Experimental Design

A large east to west transect was established that crossed different rangeland landscapes and ecosystem types: alpine meadow, alpine steppe and alpine desert. Three regions were selected along the transect that represented the three rangeland types as classified by the Chinese Rangeland Resources Distribution Map released by Animal Husbandry and Veterinary Medicine Division at Ministry of Agriculture, China (Anonymous, 1997). Qumalai was selected for alpine meadow, Palgon for alpine steppe, and Wudaoliang for alpine desert (Table 1). In each site, six 1-km2 sites were randomly selected from the geographic map. Within each 1-km2, three plots were established as repeat, and in each repeat three 30-m diameter subplots were randomly selected. The plant survey was carried out in nine 1-m2 subplots within each 30-m2 plot using the methods of Hankins et al. (2004), Figure 1.

Table 1. Location and grassland types of study areas on the Qinghai-Tibet Plateau, China.

		Qumalai	Palgon	Wudaoliang
Geographical status	Latitude (N°)	34.08~34.15	31.30~31.44	35.27~35.28
	Longitude (E °)	95.11~96.11	90.02~90.03	93.21~93.23
	Altitude (m)	4467~4709	4715~4936	4571~4580
Meteorological status	Annual precipitation (mm)	428.0	338.0	308.5
	Growing season precipitation (mm)	376.0	308.9	284.0
	Annual mean temperature (℃)	-1.7	-0.2	-5.0
	Growing season mean temperature (℃)	6.6	7.0	3.3
	Accumulated temperature above 0℃ (℃)	1074.8	1159.7	555.3
Vegetation status	Rangeland type	Alpine meadow	Alpine steppe	Alpine desert

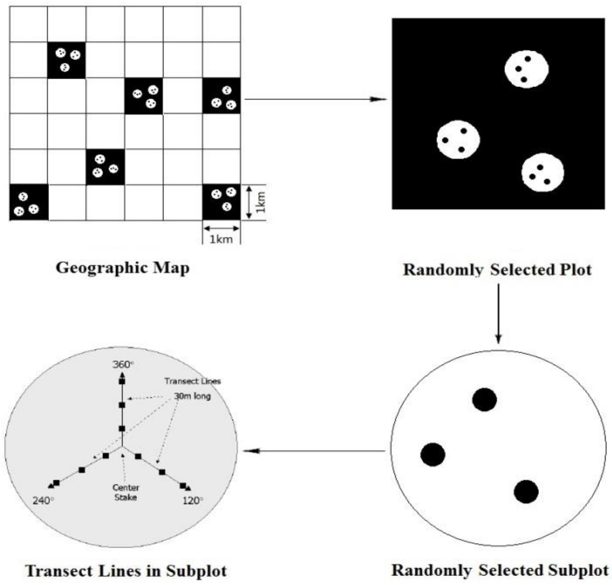

Figure 1. Schematic of sampling site selection for vegetation analysis of alpine grasslands on the Qinghai-Tibet Plateau, China.

Field Survey and Laboratory Methods

Vegetation surveys took place during the growing season in 2013. All plant species in each subplot were recorded by using species-areas methods (Dong, 1997) before sampling. In each transect of the subplot, we placed three 1m×1m quadrats in an equal distance (10 m). We recorded all plant species which presented in each quadrat, and the abundance of each species was also measured respectively.

Soil samples were collected from four layers: 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm depths. In each subplot, two composite samples were obtained, which were mixed by three replicates, and one sample was for soil moisture (SM) and soil bulk density (SBD), measured by the methods outlined by Huang (2000); the other was for soil pH and electrical conductivity (EC), which were carried out in 1:5 soil-water extracts with the use of a glass-membrane electrode.

Data Calculation

The plant diversity was calculated using the species richness (R), the Shannon-Weiner index, an integrated index of diversity, (H'), the Pielou index of evenness (J), and the Simpson index of dominance (D). These indices were calculated using the following methods:

$$H' = -\sum_{i=1}^{n} P_i \log_2 P_i \quad \text{Equation 1}$$

$$J = H'/\ln S \quad \text{Equation 2}$$

$$D = 1 - \sum_{i=1}^{n} P_i^{\,2} \quad \text{Equation 3}$$

$$R = S \quad \text{Equation 3}$$

Where P_i = relative abundance of species i; S = the total number of species in a certain quadrat; N = the sum of individual numbers of all species in the quadrat.

Statistical Analysis

The differences of the plant diversity indices and soil physical properties across different types of grassland were statistically analyzed using one-way ANOVA in SPSS 17.0. We also used SPSS 17.0 to statistically analyze the correlation between plant diversity indices and soil physical variables through two-tailed t test ($P<0.05$, $P<0.01$).

Results and Discussion

Dynamics of Soil Physical Properties in Alpine Grasslands

The soil physical properties varied across grassland types (Figure 2). As the results of low organic matter and high salt, the soil of alpine desert steppe was more alkaline (pH > 8.5) than other two grassland types. In addition, thanks to the effects of vegetation litter and root exudates, the soil pH was lowest at the surface. With the constant deepening of the soil, the pH value showed the upward trend, particularly the types of alpine meadow and steppe, whereas there was no significant increase across the soil layers in alpine desert steppe.

Soil EC had significantly relationship with salts. Caused by the salt concentrations, the order of EC values among grassland types were alpine desert steppe, alpine steppe and alpine meadow. Similar with pH, the EC value increased with deepening of the soil, and this was mostly due to the leaching of salts. Besides, the soil EC showed a relatively rapid rise from the layer of 5-10 cm to 15-20 cm in alpine meadow and steppe.

As for meteorological features, the precipitation on alpine meadow was significantly higher than alpine steppe and desert steppe, but the evaporating intensity was on the contrast. Under the combined impact of water income and expense, the SM value of alpine meadow showed 17 to 31 times higher than alpine steppe and desert steppe. As the soil layer deepen, the effects of meteorological factors on SM became weaker, instead, the effects of soil water retention determined by soil structure and composition turned to be stronger. Alpine meadow soil and steppe soil with good water retention property, the soil water accumulated and peaked at the layer of 5-10 cm. However the SM of alpine desert steppe peaked at 10-15cm, due to the water evaporation and infiltration. The alpine meadow subsoil (15-20 cm) was supplied more by underground water rather than the surface precipitation because of its strong water retention property, but the situation was the opposite in alpine desert steppe.

Instead, SBD of the alpine meadow was significantly lower than other types in each soil layer, since the meadow soil was sufficiently loose and rich in organic matters, besides the long and dense plant roots were another key influence factors. Thus for SBD, alpine steppe ranked the first relying on its small soil porosity, and alpine desert steppe was the second with big soil porosity and high gravel content (Yang et al. 2011). Besides, for alpine meadow and alpine desert steppe, the SBD bottomed at the 5-10 cm layer, whereas it was the peak of alpine steppe.

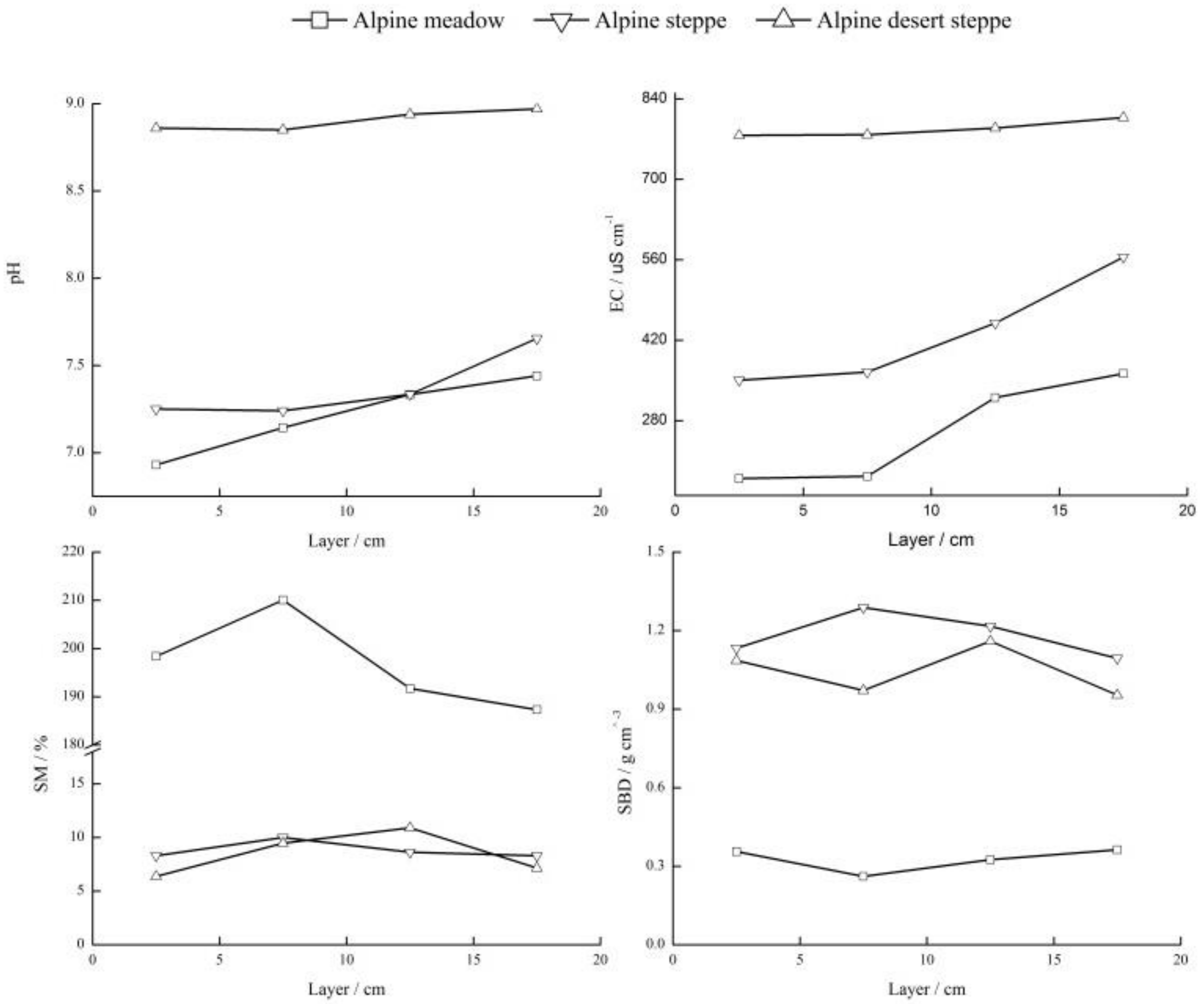

Figure 2. Soil physical properties in alpine grassland ecosystems
Note: *SM* soil moisture (%), *SBD* soil bulk density (g cm^{-3}), *EC* soil electrical conductivity ɉʈ3 Ã Í $^{-1}$).

Heterogeneity of Plant Diversity among Grassland Types

Plant diversity varied greatly among grassland types as well (Figure 3). Among all the four plant diversity indices, species richness was the most heterogeneous index across grasslands, in which significant difference was shown between any two grassland types. Overall, alpine meadow was the richest in species, alpine desert steppe ranked the second, and alpine steppe was the last. For Shannon-Weiner index, alpine meadow and desert steppe were significantly higher than alpine steppe, but there was no significant difference between two greater types. Similar with the above two plant index, the Simpson index in alpine steppe was the lowest of all, and its difference with meadow had reached significant level. In addition, neither alpine meadow nor alpine steppe had significant differences with alpine desert steppe. Pielou index was the least heterogeneous index, and little differences were shown on Pielou index among different grassland types.

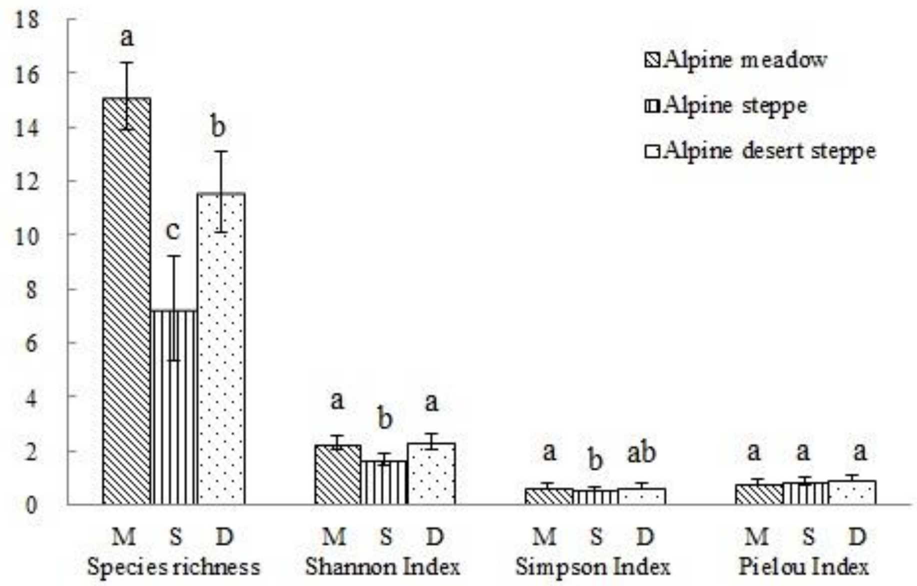

Figure 3. Plant diversity in three different alpine grassland ecosystems
Note: 1) M Alpine meadow, S Alpine steppe, D Alpine desert steppe. 2) Lowercase letters represent differences among grassland types on each plant diversity index, and different letters indicate significantly differenÔ ÁÔ ÔÈÅ 0Sπ8πυ ÌÅÖÅÌ8

The Relationship between Soil Physical Properties and Alpine Plant Diversity

The relationships between soil physical properties and alpine plant diversity were shown in Table 2. The SM was more strongly correlated to species richness than other plant indices in each soil layer, and their ÃÏÒÒÅÌÁÔÉÏÎ ÃÏÅÆÆÉÃÉÅÎÔÓ ×ÅÒÅ ÂÅÔ×ÅÅÎ π8ψωφ ÁÎÄ π8ωσς ÁÔ ÓÉÇÎÉÆÉÃÁÎÔ ÌÅÖÅÌ ¡0Sπ8πυ¢8 "ÅÓÉÄÅÓh ÔÈÅ 3- ÏÆ υ-10 cm layer had the strongest correlation with species richness among all the four soil layers.

Table 2. 0ÅÁÒÓÏÎȭÓ ÃÏÅÆÆÉÃÉÅÎÔÓ ÏÆ ÃÏÒÒÅÌÁÔÉÏÎ ÂÅÔ×ÅÅÎ ÓÏÉÌ ÐÈÙÓÉÃÁÌ ÐÒÏÐÅÒÔÉÅÓ ÁÎÄ ÐÌÁÎÔ ÄÉÖÅÒÓÉÔÙ

	Layer	Species Richness	Shannon-Weiner Index	Simpson Index	Pielou Index
SM	0-5 cm	0.925*	0.521	0.483	-0.273
	5-10 cm	0.932*	0.521	0.476	-0.279
	10-15 cm	0.896*	0.551	0.504	-0.205
	15-20 cm	0.908*	0.516	0.446	-0.261
SBD	0-5 cm	-0.937*	-0.558	-0.518	0.229
	5-10 cm	-0.974**	-0.714	-0.681	0.027
	10-15 cm	-0.911*	-0.581	-0.543	0.175
	15-20 cm	-0.919*	-0.645	-0.587	0.083
pH	0-5 cm	-0.243	0.168	0.208	0.672
	5-10 cm	-0.123	0.303	0.351	0.676
	10-15 cm	-0.033	0.370	0.403	0.577
	15-20 cm	-0.230	0.204	0.260	0.665
EC	0-5 cm	-0.433	0.029	0.088	0.754
	5-10 cm	-0.407	-0.016	0.039	0.616
	10-15 cm	-0.300	0.025	0.038	0.394
	15-20 cm	-0.584	-0.192	-0.138	0.619

Note: SM soil moisture (%), SBD soil bulk density (g cm^{-3}), EC soil electrical conductivity (ɛ3 Ã Í $^{-1}$).
* P<0.05, ** P<0.01

For SBD, species richness was still the unique plant diversity index which had significant correlations with it ¡0Sπ8πυ¢8)Î ÃÏÎÔÒÁÓÔ ÔÏ 3-h ÔÈÅ 3"$ ÉÎ ÅÁÃÈ ÓÏÉÌ ÌÁÙÅÒ ×ÁÓ ÃÏÒÒÅÌÁÔÅÄ ÔÏ ÓÐÅÃÉÅÓ ÒÉÃÈÎÅÓÓ ÎÅÇÁÔÉÖÅÌÙ8)Î addition, the layer of 5-ρπ Ãí ×ÁÓ ÓÔÉÌÌ ÔÈÅ ÈÉÇÈÅÓÔ ÃÏÒÒÅÌÁÔÅÄ ÓÏÉÌ ÌÁÙÅÒ ÆÏÒ 3"$h ÁÎÄ ÉÔÓ 0ÅÁÒÓÏÎȭÓ ÃÏÅÆÆÉÃÉÅÎÔ ÏÆ ÃÏÒÒÅÌÁÔÉÏÎ ×ÉÔÈ ÓÐÅÃÉÅÓ ÒÉÃÈÎÅÓÓ ×ÁÓ ÁÓ ÈÉÇÈ ÁÓ π8ωχτh ÒÅÁÃÈÉÎÇ ÁÎ ÅØÔÒÅÍÅÌÙ ÓÉÇÎÉÆÉÃÁÎÔ ÌÅÖÅÌ ¡0Sπ8πρ¢8

Both soil pH and soil EC correlated to species richness negatively, but almost the opposite to the other three plant diversity indices. However, none of their correlations had reached the significant level in any soil layer.

Conclusion

Each grassland type had its own changing pattern of physical properties across soil layers since the particular structure and composition. As the supporter of plant, soil environment had big impact on aboveground vegetation. In this study, we demonstrated that some soil physical properties (SM and SBD) were key factors which led to the alpine plant heterogeneity across grassland types.

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