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黄土丘陵区地形、土壤水分与草地的景观格局

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摘要 :在黄土丘陵区 ,地形因素和土壤水分是决定草地景观格局的主要因素 ,同时草地景观格局在不同尺度上影响着景观中的流。地形因素、土壤水分和草地结构在不同尺度上有着密切的联系 ,研究它们之间的关系对于了解生态系统的过程十分重要。针对黄土高原异质化的草地群落结构 ,选取黄土丘陵区经过 20 多年自然封育形成的天然草地 ,从坡面尺度对景观格局进行了调查研究 ,在地形因素、土壤水分和草地结构中选取了有代表性的指标 14 个 ,用多元统计分析对选取的指标进行了主成分分析和聚类分析。聚类分析将样方分成 3 种植被类型 ,不同植被类型的海拔、坡度、20～140cm 土壤含水量以及物种丰富度和生物多样性存在显著性差异。相关分析表明 :海拔对 0～300cm 土壤含水量影响显著 ;海拔对草地群落盖度 ,坡位、坡向对草地群落的物种丰富度和生物多样性有着重要影响 ;而草地群落的物种丰富度和生物多样性与 0～100cm 土层的含水量关系密切。

关键词 :黄土丘陵区 ;地形因素 ;土壤水分 ;草地景观格局 ;多元统计分析

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Reciprocal relationships between topography, soil moisture, and native vegetation patterns in the loess hilly region, China

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Abstract : In loess hill landscapes , the pattern of vegetation affects movement of water and soil across the landscapes at multiple scales ; likewise topography and soil moisture influence the structure of the plant community. At smaller scales , soil moisture is heterogeneous. Small-scale heterogeneity has a large impact on the performance of individual plants , and therefore it influences the structure and dynamics of plant populations and communities. These relationships must be studied in order to gain an understanding of the ecosystem dynamics. We investigated at the slope scale the community structure of natural grassland on the Loess Plateau. The study site had been fenced off for more than 20 years. We selected 14 topography , soil moisture , and community structure metrics. Through the use of multivariate statistics (principle component analysis and cluster analysis) and canonical correlation analysis , we explain the complex relationships between topography , soil moisture and community structure.

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Three community types were identified by cluster analysis, distinguished by significant differences in elevation, slope, soil moisture at the 20 — 140cm depth, species richness, and Shannon-Wiener index. Correlation analysis indicated that elevation impacted community coverage, and slope position and slope aspect affected biodiversity of the plant community. Elevation and slope position influenced soil moisture at 0 — 300cm depth, while the biodiversity of the plant community had a reciprocal relationship with soil moisture at 0 — 100cm depth.

Key words: loess hill region; topography; soil moisture; vegetation pattern; multivariate statistical analysis

Understanding the fundamental mechanisms and spatial dynamics and variability of ecological flows of materials (including organisms), energy, and information across landscape mosaics is essential to landscape ecology. Soil moisture is a major factor influencing fundamental ecosystem processes such as photosynthesis, respiration, and nutrient uptake[1]. Moisture acts as a primary constraint on plant productivity[2-5], and affects species composition[6]. It influences erosion[7], pedogenesis[8], geomorphology[9], and infiltration-runoff partitioning in response to precipitation events[10]. Neave and Norton, for instance, find a correlation between soil moisture and forest species distribution in southern Australia[11], and Stephenson argues that actual evapotranspiration is better correlate with vegetation distribution than temperature at a range of scales[6].

Vegetation pattern plays an important role in controlling spatial patterns of soil moisture by influencing the infiltration, runoff and evapotransipiration, particularly during the growth season[12-18]. Meanwhile, terrain indices aim to represent the key hydrological processes controlling the spatial distribution of soil moisture in a simplified but realistic way[9,17-19]. The relationships between soil moisture and topography attributes at this small catchment scale were found to be very variable by Famiglietti[20]. In some cases there is a significant relation but in many other cases the relationship is insignificant[21-29]. This may be due to differences in climate, topography, soil, vegetation, scale, time and depth of sampling methods[20].

In the ecological community, the importance of topography and topography-related variation in local site conditions for community structure, composition and successional pathways is well established[30-35]. Topography shapes pattern indirectly through its influence on disturbance regimes and potential successional pathways, and directly, by creating permanent natural breaks in vegetation pattern[36,37].

However, while some studies have integrated soil moisture dynamic and its interactions with topography and vegetation pattern[38-42], our understanding of how topography, soil moisture, and vegetation dynamics interact to form landscape pattern is still limited. The relationships between topography, soil moisture, and vegetation have usually been studied in terms of an ecosystem's response to environmental extremes rather than as a response to a gradual transition in land cover or patchiness. In this study, we use an alternative approach of examining the relationships between soil moistures, topography and vegetation pattern, by describing the full range of ecological variability at a typical slope scale in Loess Plateau, China. In hilly areas of the Loess Plateau, geomorphology is complex and highly variable soil moistureis the main determinant of plant growth[43,44]. Topography and soil moisture thus influence vegetation patterns across the landscape, while these patterns themselves have a strong effect on soil water use and movement. It is therefore necessary to study relationships between topography, soil moisture and plant community structure in order to understand ecosystem functions and processes in these areas. Due to specifics of the local geography and climate, combined with a long history of agriculture in the region, the primal vegetation is so disrupted that most ecological research in the area has concentrated on artificial forests and grasslands. Studies of the natural grassland are few. The natural grassland is a complex adaptive system, with community type, species composition, and biodiversity evolving and interacting in response to particulars of the local topography and soil moisture. The topography and soil moisture patterns therefore likely differ from those in artificial grassland. In this research, we investigate at the slope scale the community structure of nature grassland, which has been fenced off from surrounding agricultural land in the loess hills area for more than 20 years. Field observations were analyzed for quantitative relationships between topography, soil moisture and plant community structure.

Therefore, the objectives of this paper are (1) to understand the relative roles of community structure and topographic attributes in controlling the observed spatial variability of the soil moisture; (2) to analysis the influence of topographic indices on the vegetation pattern at a slope scale in nature grassland; (3) to explain the infection of soil moisture on the community structure of nature grassland.

1 Material and methods

1.1 Study area

The study was conducted at Wangwa town in the western part of Pengyang county in the Ning Xia Autonomous Region, China. The study area is situated on the middle part of the Loess Plateau, and is located at 106°32′45″—106°33′15″E, 36°04′30″—36°09′36″N. The region has an altitude of 1684—1890 m, soil slopes of 15°—40°, and has a semiarid continental climate with an averaged annual temperature of 7.2 ℃, average annual evaporation of 1400mm, and a frost-free growing season of 112—140 d and an average of 2110 h of sunshine each year. The mean annual precipitation is 450 mm with great inter-annual variability and 65 % of the rain falls in July, August and September. There is significant topographic variability with typical loess hills and gully slope shapes within the study area. The soils, developing on wind-accumulated loess parent material, are thick at an average of 50—80 m. The most common soil in the study area is loessial with silt content ranging from 64 to 73 % and clay content varying from 17 to 20 %. The soil is weakly resistant to erosion. The erosion rate is high at about 10000—12000 ton $\cdot km^{-2}a^{-1}$. This research site, representative of the grassland region, has been fenced off since 1984. The primary herbaceous plants in the study area are *Stipa bungeana*, *Heteropappus altaicus*, *Arthraxon hispidus*, *Medicago lupulina*, *Stipa grandis*, *Androsace erecta*, *Artemisia sacrorum*, *A. capillaries* and *A. frigida*.

1.2 Data collection

1.2.1 Sampling methods

In order to better understand relationships between topography, soil moisture and plant community structure at the slope scale in loess hilly region, four V-shaped transects were established with the interval of 50m (Fig. 1). Each "V" had one sunny and one shaded slope. Transects extended from the top to the bottom of hills located adjacent to the Soil and Water Conservation Station of in Wangwa, Pengyang County. Samples measuring 1m ×1m were sited every 5m of altitude change along each transect, giving 15 shaded and 20 sunny samples in each V for a total of 140 samples.

1.2.2 Survey methods

(1) Plant data and Environmental attributes survey

In late August, the peak biomass time period, we measured plant species composition, coverage, average height and above-ground biomass for each sampling site. Average height was weighted by species coverage. We then harvested plants at the soil surface, bagged and weighed them, then dried them for 20h at 80 ℃ before measuring their dry weight. Note that this measure of above-ground biomass includes the standing crop, but not the litter or any standing dead plants. Each sampling site was surveyed and its environmental characteristics were recorded. The environ-mental attributes assessed are: hillslope position, aspect, elevation (recorded

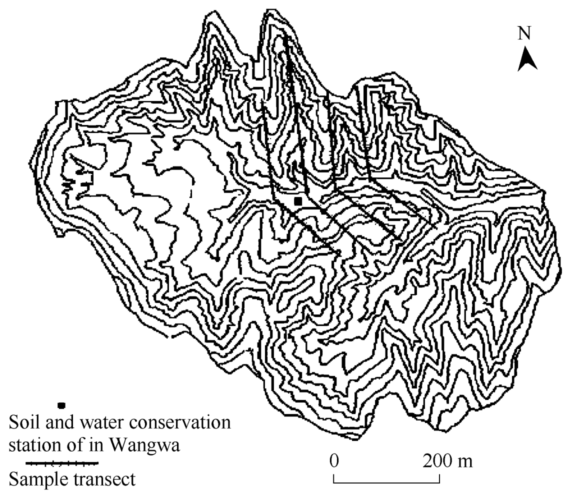

Fig. 1 Spatial distribution of sampling transects

by elevation instrument) and slope degree on each site.

(2) Soil moisture measurement

Soil samples were taken in the center of each plot. All soil samples were weighed the same day that they were collected, and all soil sampling was accomplished within a period of seven rain-free days. Sampling was done with a 5 cm diameter screw auger, taking samples in 20cm increments down to 3m. Samples were weighed in moist condition, then dried at 105 ℃ to a constant mass. At each sample site two measurements were performed to measure moisture content at fifty depths: 0—20, 20—40, 40—60, 60—80, 80—100, 100—120, 120—140, 140—160, 160—180, 180—200, 200—220, 220—240, 240—260, 260—280 and 280—300 cm. The mean of the two measurements is the soil moisture content at each depth on the sample site.

1.3 Initial data processing

The number of species was counted to indicate the species richness, and the Shannon-Wiener index (H) was calculated to show species diversity. The Shannon-Wiener index is given as

$$H = -\sum (P_i \times \ln P_i)$$

where $P_i = N_i / N$ and $N = \sum N_i$. N_i denotes the coverage of species i within a plot, rather than the number of individual plants of species i, because some herbaceous plants were so ramified that individual plants could not be distinguished and counted.

1.4 Statistical analysis

All statistical analyses described below were performed using SPSS software.

1.4.1 Principal component analysis

Principal Component Analysis (PCA) reduces multiple variables to a small number of composite variables, while minimizing loss of information. The composite variables summarize the majority of the information in the original data, decrease the number of variables, and encapsulate some internal relations among the original variables. We used PCA to eliminate redundant factors, and enhance the accuracy of the subsequent Cluster Analysis.

A total of 14 metrics were recorded from all 140 plots, with the data describing plot topography, soil moisture, and plant community structure. The topography variables were slope, slope aspect, elevation, and slope position. Soil moisture variables were mass soil moisture at depths of 0—20cm, 20—60cm, 60—100cm, 100—140cm, 140—200cm and 200—300cm. The plant community structure indices were coverage, biomass, species richness and Shannon-Wiener index. Non-numerical classification variables were assigned numerical values by empirical formulas. For example, a sunny slope was assigned aspect 0.3, a partially shaded slope 0.5, a mostly shaded slope 0.8, and a slope in full shade 1.0. Similarly, an up-slope plot was assigned position 0.4, a mid-slope 1.0, and a down-slope 0.8[45]. In order to have PCA work with indices of similar magnitude, the initial data was standardized. Because the initial (raw) data was found to be normally distributed, it could be standardized using the method of Z scores. At that point, PCA was used to calculate the eigenvectors and eigenvalues.

1.4.2 Cluster Analysis

Cluster Analysis is a multivariate statistical technique for classifying objects according to their characteristics. Given the multiple characteristics of each sample, similarities among them are ascertained, and then samples with similar characteristics are clustered together. Samples are multiply classified from large to small differences, resulting in a similarity tree or dendrogram[45]. In this study, the 140 plots were classified by Ward's method, which recognizes that information can occur in different categories. We categorized input variables as relating to topography, soil moisture, or plant community structure. Ward's method was chosen because it minimizes intra-category discrepancies and maximizes inter-category discrepancies.

2 Results

2.1 Data reduction

Four eigenvalues were greater than one (Table 1), having values of 5.09, 3.01, 2.00 and 1.54. Eigenvectors corresponding to these eigenvalues respectively explained 37.03%, 25.03%, 15.75% and 9.69% of the data's variance, so they cumulatively explained 87.5% of the variance. In the first principal component, the loading capacities of soil moistures of 20—60cm (0.90), 60—100cm (0.96) and 100—140cm (0.86) were the greatest, so this component mainly encapsulates the role of soil water. The second principal component's greatest loading capacities were elevation (0.74) and slope aspect (0.73), so it was primarily about topography. In the third principal component, loading capacities for biomass (0.84) and coverage (0.68) predominated, representing the productivity of the grassland. In the fourth principal component, species richness (0.89) and the Shannon-Wiener index (0.59) had the greatest loading capacities, representing the grassland's biodiversity.

As the eigenvalues show, no single principal component explains a large proportion of the variance. This indicates that the heterogeneous landscape pattern is the combined result of many factors in this topographically complex region. In such a case we should expect extensive reciprocity among the factors contributing to the landscape pattern.

Table 1 Factor loadings in four principal components. Eigenvalues, % of variance and Cumulative % of four principal components in principal component analysis

Factors	Principal components			
	I	II	III	IV
Shannon-Wiener index (*H*)	0.02	0.12	0.00	0.59
Species richness	0.15	0.32	0.13	0.89
Elevation	-0.54	0.74	0.06	-0.05
Slope	-0.30	0.32	-0.46	-0.23
Position	0.27	0.57	-0.08	0.02
Aspect	-0.13	0.73	-0.08	-0.15
Coverage	-0.06	0.23	0.68	-0.31
Biomass	-0.17	-0.09	0.84	0.14
SW0-20	0.51	0.21	0.15	-0.09
SW20-60	0.90	0.16	0.10	-0.09
SW60-100	0.96	0.05	0.09	-0.07
SW100-140	0.86	-0.06	-0.05	-0.06
SW140-200	0.62	-0.11	-0.07	-0.06
SW200-300	0.42	-0.21	-0.12	-0.08
Eigenvalue	5.09	3.01	2.00	1.54
% of variance	37.03	25.03	15.75	9.69
Cumulative (%)	37.03	62.06	77.81	87.50

2.2 Plots Cluster

Following the Principal Component Analysis, we selected those factors with the greatest information content from each principal component. Three soil water variables were selected based on the first principal component, representing depths of 20—60cm, 60—100cm and 100—140. Elevation and slope aspect were picked given the loading in the second principal component. The productivity indices biomass and coverage were chosen based on the third principal component, and species richness and the Shannon-Wiener diversity index were selected due to the fourth principal component. These nine factors were used in a cluster analysis of the 140 plots. And the 140 plots were clustered into three types, which denoted Ⅰ: *Heteropappus altaicus*, Ⅱ: *Stipa bungeana* and Ⅲ: *Arthraxon hispidus* communities respectively.

The three community types differ significantly in elevation and slope (Table 2). Type Ⅰ (*Heteropappus altaicus*) consists mostly of down-slope plots with relatively low elevation and slope. Type Ⅱ (*Stipa bungeana*) Type Ⅲ (*Arthraxon hispidus*) was generally mid- and upper-slope, with a higher average altitude.

Soil moistures also varied systematically among community types (Table 3). Specifically, soil water content presented as type Ⅲ < type Ⅱ < type Ⅰ. This difference in soil moisture is probably attributable to topography, because type I plots were lowest in elevation. The coverage and biomass did not differ notably with community types, but species richness and the Shannon-Wiener index differed significantly (Table 4). There were a total of 40 species represented across all type Ⅰ plots, with an average of 14 species per plot. Community type Ⅱ contained a total of 39 species, with an average of 11 appearing in each plot. Finally, type Ⅲ comprised 32 species, and community type Ⅲ averaged 10 species per plot. Community type I clearly contained a greater average number of species, likely due to their greater soil water content.

Table 2　The difference of topography features in three community types

Community type	Elevation (m) ($\mu \pm \sigma$)	Number of plots at slope position			Number of plots with aspect:		Slope (°) ($\mu \pm \sigma$)
		Up	Middle	Down	Shady	Sunny	
Ⅰ (*Heteropappus altaicus*)	1704 ±14.6	0	8	44	40	12	19.9 ±11.7
Ⅱ (*Stipa bungeana*)	1745 ±20.5	14	10	6	8	22	30.0 ±14.5
Ⅲ (*Arthraxon hispidus*)	1783 ±10.5	26	22	10	12	46	27.3 ±10.7
P value	0.00						< 0.01

$\mu \pm \sigma$ denotes average ±standards deviation; *P* value suggests significance level

Table 3　The difference of soil moisture of different soil layers within the three community types

Community types	Number of plots	SW_{0-20}	SW_{20-60}	SW_{60-100}	$SW_{100-140}$	$SW_{140-200}$	$SW_{200-300}$
Ⅰ (*Heteropappus altaicus*)	15	9.3 ±1.4	9.0 ±1.4	8.6 ±1.2	8.5 ±1.0	9.3 ±1.1	9.3 ±1.3
Ⅱ (*Stipa bungeana*)	35	9.1 ±0.6	8.3 ±0.3	8.3 ±0.5	8.1 ±0.8	9.0 ±0.4	8.9 ±0.6
Ⅲ (*Arthraxon hispidus*)	20	8.9 ±0.5	7.1 ±0.5	7.0 ±0.4	7.7 ±0.4	8.7 ±0.4	8.7 ±0.5
P value		0.10	0.01	0.01	0.03	0.07	0.08

$\mu \pm \sigma$ denotes average ±standards deviation; *P* value suggests significance level

Table 4　The difference of community structure within the three community types

Plot types	Dry biomass (kg/m^2) ($\mu \pm \sigma$)	Coverage (%) ($\mu \pm \sigma$)	Shannon-Wiener index ($\mu \pm \sigma$)	Species richness ($\mu \pm \sigma$)
Ⅰ (*Heteropappus altaicus*)	0.11 ±0.03	66.3 ±10.1	2.13 ±0.42	14 ±3
Ⅱ (*Stipa bungeana*)	0.09 ±0.10	59.9 ±15.4	1.98 ±0.20	11 ±1
Ⅲ (*Arthraxon hispidus*)	0.11 ±0.09	60.3 ±13.1	1.90 ±0.27	10 ±2
P value	0.16	0.26	0.02	0.00

$\mu \pm \sigma$ denotes average ±standards error; *P* value suggests significance level

Table 5　Correlation coefficients between topography and soil water, topography and community structure

Topography	Coverage	Biomass	Richness	Isw	SW_{0-20}	SW_{20-60}	SW_{60-100}	$SW_{100-140}$	$SW_{140-200}$	$SW_{200-300}$
Slope	-0.20	-0.45*	0.02	0.04	0.04	0.03	-0.07	-0.20	-0.20	-0.26
Elevation	-0.25*	0.09	-0.17	0.05	-0.56**	-0.59**	-0.82**	-0.85**	-0.85**	-0.85**

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

Table 6　The difference of community structure and soil water within the two aspect types

Aspect	Coverage	Biomass	Richness	Isw	SW_{0-20}	SW_{20-60}	SW_{60-100}	$SW_{100-140}$	$SW_{140-200}$	$SW_{200-300}$
Shady	63.9 ±14.0	0.3 ±0.1	11 ±2	2.0 ±0.2	9.4 ±1.3	8.7 ±1.1	8.1 ±1.1	7.6 ±1.3	7.5 ±1.2	7.3 ±0.6
Sunny	75.5 ±9.0	0.3 ±0.1	13 ±2	2.2 ±0.2	11.1 ±0.5	10.3 ±0.4	9.7 ±0.2	8.6 ±0.6	8.0 ±1.0	7.4 ±0.4
P value	0.00	0.77	0.00	0.16	0.00	0.00	0.00	0.14	0.48	0.79

Table 7　The difference of community structure and soil water within the three slope positions

Position	Coverage	Biomass	Richness	Isw	SW_{0-20}	SW_{20-60}	SW_{60-100}	$SW_{100-140}$	$SW_{140-200}$	$SW_{200-300}$
Up	68.8 ±13.3	0.4 ±0.1	11 ±2	2.0 ±0.2	8.9 ±0.6	7.8 ±0.7	7.1 ±0.4	6.0 ±0.3	6.0 ±0.5	6.6 ±0.3
Middle	69.0 ±18.1	0.3 ±0.1	12 ±3	1.9 ±0.4	10.2 ±1.5	9.3 ±1.1	9.4 ±0.5	9.3 ±0.3	8.7 ±0.3	7.9 ±0.2
Down	68.0 ±12.4	0.3 ±0.1	12 ±2	2.1 ±0.3	10.0 ±1.2	9.6 ±0.9	8.9 ±0.9	8.0 ±0.6	7.7 ±0.7	7.4 ±0.3
P value	0.97	0.20	0.24	0.05	0.00	0.00	0.00	0.00	0.00	0.00

Table 8　Correlation coefficients between Soil water and Community structure

Community structure	SW_{0-20}	SW_{20-60}	SW_{60-100}	$SW_{100-140}$	$SW_{140-200}$	$SW_{200-300}$
Coverage	0.05	0	0.06	0.11	0.11	0.17
Biomass	-0.08	-0.08	-0.13	-0.12	-0.03	0.06
Richness	0.33**	0.34**	0.34**	0.16	0.12	0.12
Isw	0.27*	0.25*	0.14	-0.07	-0.08	-0.08

*, ** denotation is same to table 5

2.3 Relationships between topography attributes, vegetation pattern and soil moisture content

From the correlation coefficients between topography and soil water, topography and community structure (Table 5), we could see that slope had a significant correlation with grassland biomass, and elevation had very important effects on grassland community coverage and soil moisture of 0 — 300 cm. The difference of community structure and soil water within two aspects suggested that slope aspect had great influence on community coverage, species richness of community and soil moisture of 0 — 100cm (Table 6). Besides, Table 7 suggested that soil water of 0 — 300cm were effected significantly by slope position.

According to the correlation coefficients between soil water and community structure (Table 8), we knew that the species richness and biodiversity of the grassland community was closely related to the soil moisture at 0 — 100 cm depth, which might attribute that the soil at 0 — 100 cm depth was the main distribution range of root systems of herbaceous species. It suggested that there were a reciprocal interaction between the soil moisture at 0 — 100 cm depth and the biodiversity of the grassland community.

3 Discussion

In this research, 14 metrics about topography, soil water and community structure were chosen, and 140 plots investigated were classified into three community types by using PCA and Cluster Analysis. Discrepancies in elevation, slope gradient, soil moisture of 20 — 140cm, species richness, Shannon-Wiener index were significant in three community types. Type Ⅰ was dominated by *Heteropappus altaicus* community, and the species richness and biodiversity were the biggest. It attributed that most plots of this type were located in down-slope with low altitude and slope gradient, and more soil water, which played controlling roles in the species survival and reproduction. Type Ⅲ was *Arthraxon hispidus* community, in which the species richness and biodiversity was the lowest in the three types. The reason was that the majority of plots located in up-slope with high elevation, steep slope and low soil moisture. Type Ⅱ was *Stipa bungeana* community, and most of plots distributed in the middle of sunny slope, and the soil moisture and biodiversity were intervenient in those three types.

Numerous studies suggested that topography played an important role in the forming of vegetation landscape pattern. By redistributing resources, such as light, heat, water and so on, topography impacted on matter flows across landscape elements, and dominated many of the biotic and abiotic processes along topography gradient, thereby influenced on the forming of landscape pattern[39,46-50]. Our research showed that elevation had a great affect on soil moisture at the depth of 0 — 300cm, and topography factors such as elevation, slope gradient and slope aspect had a close relationship with coverage, species richness and biodiversity of community at the slope scale, which mainly attributed that altitude, slope and slope aspect had an important influence on the matter flows across landscape elements. Generally, the position with high elevation and precipitous slope would receive less surface runoff and stream in soil from higher place, and contrarily the position with low elevation and slope would obtain more water. In addition, nutrient elements such as soluble nitrogen, soluble phosphorus and soluble potassium, generally flowed following the water, and gave arise to nutrient migration, thereby formed different habitat conditions along topography gradient. During the restoration process of vegetation, an increase of species richness and biodiversity not only depended on the habitat condition, but also lay on the seed availability. Usually, the surface runoff could give arise to migration of seeds and propagulums in a certain habitat, and became the new species in the habitat, which was another important reason for discrepancy of species richness and biodiversity caused by topography.

Specifically, soil moisture had been considered the most limiting factor for the vegetation landscape pattern in the semiarid area, which had an important influence on the species distribution, vegetation formation, and vegetation productivity[2,3,51-53]. Likewise vegetation changes exerted a control in the vertical water fluxes between the atmosphere, land surface and subsurface[54~57]. As early as 1947, Watt had found that vegetation pattern could control microclimate condition[55]. Large number of researches indicated that plant cover structure, including surface roughness of the canopy and the root systems, could modify the water cycling in a landscape influencing the partitioning of its flux into evapotranspiration, surface runoff or soil percolation[56,57]. Our study showed that the species richness and biodiversity of the grassland community had a reciprocal relationship with the soil moisture at 0－100cm depth. It attributed that the soil layer of 0－100cm depth was the primary distribution range of roots in the native grassland, and then the soil moisture content of it reflected the habitat condition of the native grassland in the loess hilly region on the whole, thereby affecting the plants distribution and species richness. In the same way, the species richness and biodiversity of the native grassland impacted greatly the soil moisture at the depth of 0－100cm, which attributed that in a certain extent the species richness reflected plants cover structure and roots systems influencing the water fluxes between the atmosphere, land surface and subsurface. In the grassland with higher biodiversity, the structure of plant cover and root systems might be complex, and be able to slow down or stop surface runoff greatly, and then increase soil percolation ability and promote precipitation infiltration on the spot. In contrary, in the grassland with lower biodiversity, the structure of plant cover and root systems might be simple, and have a little influence on slowing down surface runoff, and then the soil percolation ability might be weaker and the soil moisture content was lower.

The vegetation distributions across landscapes in semiarid terrain are driven by soil moisture variation, which in turn are closely associated with the changes in topography. These vegetation changes exert a control in the vertical water fluxes. Reasonable landscape structure could be in favor of the water cycling, and enhances vegetation productivity and improves regional environment. However, unfavorable landscape structure could cause maladjustment of the water cycling, and then brings some adverse problems of environment. Our research illuminated that landscape pattern of the native grassland represented a large heterogeneity due to the influence of topography in loess hilly region at the slope scale. To this question, we should ascertain some sections in the light of topography, soil moisture and vegetation type in this area, and choose approximating nature species patterns corresponding with the sections to enhance resistance against disturbance and promote the healthy cycling of ecosystem.

However, this empirical study was only concerned with the spatial relationships between topography, soil moisture and vegetation. Of course, the temporal relationships are equally important to ecosystem restoration, and further study on spatiotemporal relationships between them, while much more intensive, may be needed to supply a better answer to the question of ecological restoration in the loess hilly region.

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